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The IJC Menomonee River Watershed Study Ground Hydrology. Volume 7

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Volume 7

EPA

The IJC Menomonee River Watershed Study

Groundwater Hydrology

Menomonee River ★

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

The Great Lakes National Program Office (GLNPO) of the U.S. EPA, was established in Region V, Chicago to provide a specific focus on the water quality concerns of the Great Lakes. GLNPO also provides funding and personnel support to the International Joint Commission activities under the U.S.- Canada Great Lakes Water Quality Agreement.

Several land use water quality studies have been funded to support the pollution from Land Use Activities Reference Group (PLUARG) under the Agreement to address specific objectives related to land use pollution to the Great Lakes. This report describes some of the work supported by this Office to carry out PLUARG study objectives.

We hope that the information and data contained herein will help planners and managers of pollution control agencies make better decisions for carrying forward their pollution control responsibilities.

Madonna F. McGrath
Director
Great Lakes National Program Office

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The research was a comprehensive study of the quantity and quality of groundwater discharged into the Menomonee River System, southeastern Wisconsin. The Menomonee River Watershed comprises three aquifer systems: the deep artesian sandstone, the Niagara dolomite and the glacial aquifers. Groundwater discharge into the river system is supplied mainly by the shallow glacial aquifer, with only a minor component of discharge supplied by the dolomite aquifer. During the 1 year study, groundwater was found to account for 45 to 65% of the non-event flow in the Menomonee River. Discharges from sewage treatment plants and of industrial waste waters supplied the remainder of the non-event flow.

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Volume 7

by

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DISCLAIMER

This report has been reviewed by the Great Lakes National Program Office of the U.S. Environmental Protection Agency, Region V Chicago, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This report is a pre-print of a U.S. Environmental Protection Agency (EPA) Technical Report. The EPA publication is to receive preferential citation.

PREFACE

This report describing the groundwater impacts on the water quality in the Menomonee River is divided into three parts to address project goals. In Part I, the groundwater loading rates to the Menomonee River System are quantified and the major contaminants carried to the river in groundwater are identified as chlorides and sulfates. In Part II, the sources of groundwater contamination in the Menomonee River Watershed are identified and the potential hazard that each represents is assessed. Suggestions are given for identifying the importance of these sources in other urban watersheds. In Part III, a predictive tool in the form of a groundwater quality model is described and tested using data from the Menomonee River watershed. The model is used to gain insight into the probable response of a groundwater system to changes in land use or management practices.

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*Detailed contents are presented at the beginning of each part.

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PART I

FIELD DATA QUANTIFYING GROUNDWATER — SURFACE WATER INTERACTION

by

C. E. EISEN
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ABSTRACT

The research was a comprehensive study of the quantity and quality of groundwater discharged into the Menomonee River System, southeastern Wisconsin. The Menomonee River Watershed comprises three aquifer systems: the deep artesian sandstone, the Niagara dolomite and the glacial aquifers. Groundwater discharge into the river system is supplied mainly by the shallow glacial aquifer, with only a minor component of discharge supplied by the dolomite aquifer. During the 1 year study, groundwater was found to account for 45 to 65% of the non-event flow in the Menomonee River. Discharges from sewage treatment plants and of industrial waste waters supplied the remainder of the non-event flow.

Urbanization is speculated to have caused a significant change in the hydrochemistry of the glacial aquifer as compared to the regional average for eastern Wisconsin. Chloride and sulfate are the dominant ions in solution, while the regional water quality is dominated by carbonates. Dissolved solids increased as much as 100% with chloride and sulfate increasing by as much as 900% and 200% respectively, over regional averages. It was estimated that groundwater accounts for 51 to 82% of the total chloride concentration found in the base flow of the Menomonee River.

Inorganic nitrogen was found in concentrations of < 1 mg/L of N. Relatively high concentrations of nitrate generally were found in the agricultural portions of the watershed while ammonia was found in the urbanized portion. Groundwater was estimated to supply from 12 to 24% of the base flow loadings of inorganic nitrogen while the remainder was discharged from sewage treatment plants. Phosphate was found in low concentrations in the groundwater.

Heavy pumpage of the Niagara dolomite and glacial aquifers from wells near the Menomonee River has caused certain reaches of the river to lose water to the shallow aquifer. Approximately 2840 m^3/d (0.75 mgd)* of stream flow is lost to the groundwater system. Bacterial analyses of the groundwater in these areas indicated severe fecal contamination. Dye tracer studies showed that some--if not all--bacteria in the groundwater may be derived from leaky sewer lines.

Although metals and other toxic chemicals were not found in significant concentrations in the groundwater, the change in hydrochemistry from carbonate to chloride/sulfate dominated waters indicates a deterioration in groundwater quality. Chloride found in the shallow groundwater system is probably

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*Millions of U.S. gallons/day.

produced from road salt runoff. Sulfate may arise from oxidation of industrially-produced sulfides or from landfills bordering stream channels. To date few base line data have been compiled for urban watersheds and the data suggest the need for additional investigations.

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I-1. INTRODUCTION

The goal of the International Joint Commission (IJC)-Pollution From Land Use Activities Reference Group is to establish quantifiable relationships between land use activities and pollutant loadings to the Great Lakes. To accomplish this goal all aspects of pollutant transport must be analyzed including direct effluent discharge, precipitation, surface runoff and groundwater discharge.

The purpose of this portion of the study is to determine the amounts of pollutants delivered to the Menomonee River by groundwater discharge. A discussion of the effects of stream water infiltration into the shallow groundwater system also is included.

The Menomonee River Watershed is part of the Milwaukee-Waukesha metropolitan area. It contains six major industrial districts and--in 1975--the population was about 337,000. More than 54% of the Watershed is devoted to urban uses (1, pp. 30-39), while the northern portion of the Watershed is primarily agricultural. In this area there are 49 animal operations, primarily dairy cattle farms (1, p. 39).

The north-south and east-west interstate highway system passes through the center of the watershed and the large network of arterial highways has influenced the location of urban development in the basin. Ease of movement and a < 30 minute travel time from outlying areas to downtown Milwaukee, has promoted recent urban development. Land use forecasts predict a 12% increase in urban land use by the year 2000 (1, p. 39).

The effects of urban and agricultural development on the water resources of the watershed are significant. The potentiometric surface in the deep sandstone aquifer, which provides the largest subsurface water supply for the area, has experienced a 107m (350 ft) decline since 1880 (2). The USGS has developed a digital computer model for the sandstone aquifer in southeastern Wisconsin (3, p. 37). Values for the potentiometric surface in the confined sandstone aquifer predicted by the model show that the aquifer will reach stable water table conditions in Milwaukee by the year 2000. The water quality of the aquifer has become increasingly saline in some areas (1, p. 303; 4).

The overlying Niagara dolomite aquifer also has been developed extensively. Large cones of depression exist around wells pumping from the dolomite aquifer. These cones of depression alter normal groundwater flow and subsequently restrict groundwater discharge into the Menomonee River (1, p. 120; 2). Pollution of the Niagara dolomite has become a major problem in southeastern Wisconsin. Landfill leachate, septic tank effluent, and agricultural and industrial discharges have been mentioned as pollution sources (1, p. 300; 2; 5).

The shallow sand and gravel aquifer overlying the Niagara dolomite, is most susceptible to contamination. After contaminants have entered the shallow groundwater system they may move into the deeper bedrock aquifer or continue to move within the shallow aquifer. To date, little analysis has been done on the water quality of the shallow groundwater system.

The surface water quality of the watershed has been most affected by human development. The Menomonee River contains high amounts of nutrients, fecal coliform bacteria, zinc and lead (1, pp. 257-262; 6). Very low dissolved oxygen levels have been recorded throughout the watershed and are indicative of organic pollution of the surface waters (1, p. 258).

I-2. CONCLUSIONS

a. In general, the local groundwater flow system is thought to be confined to the shallow glacial aquifer. Therefore, the quality of the groundwater discharged into the Menomonee River System is controlled by the quality of water in the glacial aquifer with little impact exerted from the underlying Niagara dolomite. The fine-grained material comprising the glacial aquifer combined with low recharge rates produces slow movement of groundwater, i.e., velocities of < 4 m/day.

b. Groundwater discharge to the Menomonee River System accounted for 45 to 65% of the non-event flow. Discharges from the three sewage treatment plants and industrial waste waters supply the remainder of the non-event flow. Most of the groundwater discharge to the river occurs along the lower Menomonee River, in the heavily urbanized portion of the Watershed.

c. About 4.8 km (3 miles) of the Menomonee River was losing water to the groundwater system at a rate of 2840 m^3/d (0.75 mgd). These losing reaches also receive discharges from sewage treatment plants causing degradation of surface water quality. Furthermore, little groundwater discharge occurs to dilute these nutrient-rich waters. Although water quality data indicated that the infiltrating surface water was not polluting groundwater, high numbers of fecal bacteria were found in the groundwater. Dye studies showed that leaky sewer lines could supply some bacteria to the groundwater.

d. The shallow groundwater system possesses low concentrations of nutrients and toxic metals, but high concentrations of chloride and sulfate. The concentrations of chloride and sulfate in the groundwater increased up to 900 and 200% respectively, above regional averages; causes likely are related to urban and industrial land use practices.

e. Groundwater discharge supplied 51 to 82% of the chloride and 12 to 24% of the inorganic nitrogen found during base flow conditions. A high probability exists that groundwater in other urban watersheds also discharges large amounts of chloride into streams in the Lake Michigan Basin and the combined effect may cause deterioration of the Lake's water quality.

Discharges from sewage treatment plants were found to supply most of the nutrients to non-event flow. The relatively small input of nutrients from groundwater is probably related to the small number of nutrient sources within the basin.

I-3. METHODS AND PROCEDURES

Hydrostratigraphy of the Glacial Aquifer System

The glacial and alluvial deposits in the watershed are discontinuous in lateral and vertical extent. Therefore, measurement of the elevation of the potentiometric surface and hydraulic characteristics at the 14 well sites in the watershed, offers only a general insight into the nature of the shallow groundwater flow system. Information obtained from well borings at these sites, (Appendix I-A-1), was inadequate to characterize the aquifer for the purpose of this study and several other methods were used to describe the hydrostratigraphy of the Basin:

a. Construction of a vertical variability map of the glacial deposits in the basin.

b. Construction of a sand and gravel percentage map for the watershed.

c. Determination of the stratigraphy near the Menomonee River and below its stream bed through the use of additional well logs and drill borings at sites along the Menomonee River.

d. Laboratory and field determination of the hydraulic characteristics of the glacial deposits and stream bed material at selected sites.

Vertical variability map

Vertical variability maps give the areal distribution of sand and gravel units and an indication of the depth of sand and gravel units in the subsurface. The mapping procedure involves the calculation of the weighted mean depth of sand and gravel deposits in a vertical stratigraphic section and the distribution of these units about the mean. Knowledge of the vertical location and density of sand and gravel deposits in the Watershed is important because:

a. The hydraulic conductivity of sand and gravel is 10 to 100 times greater than clay or till deposits (7, p. 53). Therefore, those regions where thick layers of sand and gravel exist can provide significant groundwater discharge to the river.

b. The minerals comprising sand and gravel deposits ($CaCO_3$ and SiO_2) are relatively inert, and have poor adsorptive capabilities for such pollutants as phosphate or metals.

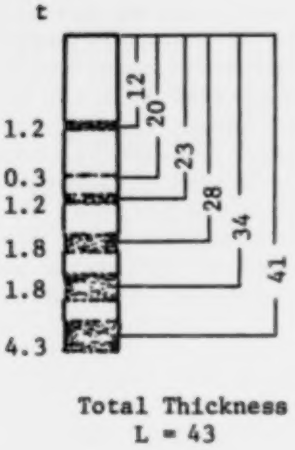
c. Pollutants can readily enter permeable deposits located close to the ground surface.

The method of mapping vertical variability in sediments was first developed by Krumbein and Libby (8) and was used successfully in mapping unconsolidated materials in Nevada (9) and Illinois (10). The method entails calculation of the statistical moments of the position of permeable units within a vertical section. The first moment is the center of gravity, or the weighted mean position of sand and gravel deposits calculated from the thickness and vertical location of these units. The second moment is the standard deviation which describes the distribution of the deposits around the center of gravity. The results of this analysis indicate the extent of permeable material in a section of the subsurface and show whether the material is distributed widely in the section or clustered about its mean depth. For example, a low center of gravity indicates that the sand and gravel is located at the bottom of the section and a low standard deviation indicates that the material is clustered about the center of gravity.

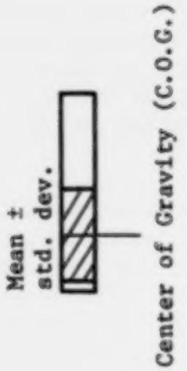
Stratigraphic information needed in the construction of a vertical variability map for the Menomonee River Basin was taken from well logs obtained during installation of observation wells, highway bridge logs obtained from the Wisconsin Department of Transportation and drillers schedules obtained from the U.S. Geological Survey. Over 200 logs were used in the compilation. Dominico and Stephenson (9) and Stephenson (10) analyzed vertical sections of 30 m (100 ft) relative to sea level. This method was not used in the present study because the glacial deposits slope steeply downward to the river and are often < 30 m thick. Thus, a 23 m (75 ft) vertical section was analyzed from the water table downward.

The method used for the calculation of the center of gravity and standard deviation is shown in Fig. I-1. Sand and gravel deposits located within the 23 m section under study were classified as having low, medium or high centers of gravity, corresponding to depths of 7.6, 15.2, or 22.9 m (25, 50 or 75 ft) below the surface. The standard deviation was characterized as low or high and should be interpreted as representing a distribution of < or > 7.6 m (25 ft) about the center of gravity. The compilation and extrapolation of these data were facilitated by the use of the computer program--Geographical Resource Analysis Software Package (GRASP). Well data were inputted to GRASP and located in 0.65 km^2 (0.25 mi^2) cell sizes. These data were then error checked and weighted before final compilation. Vertical sections which contained no sand and gravel were so identified while localities where depth to bedrock was < 15.2 m (50 ft) were designated as areas with shallow bedrock. In most of these sections bedrock is found from 3 to 6 m (10 to 20 ft) beneath the surface. The few areas in which bedrock is found from 15.2 to 22.9 m (50 to 75 ft) have no sand and gravel in the lower section and are described as having high or medium centers of gravity.

The results of the analysis are shown in Fig. I-2. The vertical variability map shows that shallow bedrock exists throughout the northern part of the Watershed. Thick clay and/or clay till deposits are found east of the Menomonee River and cover most of the area of the Watershed located in Milwaukee County. Sand and gravel deposits located in northeastern Waukesha County and in northwestern Milwaukee County are generally located from


t
1.2
0.3
1.2
1.8
1.8
4.3
12
20
23
28
34
41
Total Thickness
L = 43

Sand Number	Distance from top (h) Meters	Thickness in Meters (t)	h·t	$h^2 \cdot t$
1	12	1.2	14	173
2	20	0.3	6	120
3	23	1.2	28	635
4	28	1.8	50	1,411
5	34	1.8	61	2,081
6	41	4.3	176	7,228
Sums:		10.6	335	11,648
		(A)	(B)	(C)


Mean ± std. dev.
Center of Gravity (C.O.G.)

h = Distance from top of column to the middle of any sand unit

t = thickness of sand unit in terms of the distance h

$$\text{Center of gravity } B/A = \frac{335}{10.6} = 31.6$$

$$\text{Relative center of gravity} = \frac{\text{C.O.G.}}{L} \times 100 =$$

$$100 \times \frac{31.6}{43} = 73.5\%$$

$$\text{Approximate variance} = \frac{C - (B^2/A)}{A} = 100.1$$

$$\text{Approximate standard deviation} = \sqrt{\text{a.v.}} = 10$$

Relative standard deviation =

$$\frac{\text{ap. std. dev.}}{\text{tot. thickness}} \times 100 = \frac{10}{43} \times 100 = 23\%$$

Fig. I-1. Calculation by the vertical variability method. Taken from Stephenson (10) after Krumbein and Libby (8).

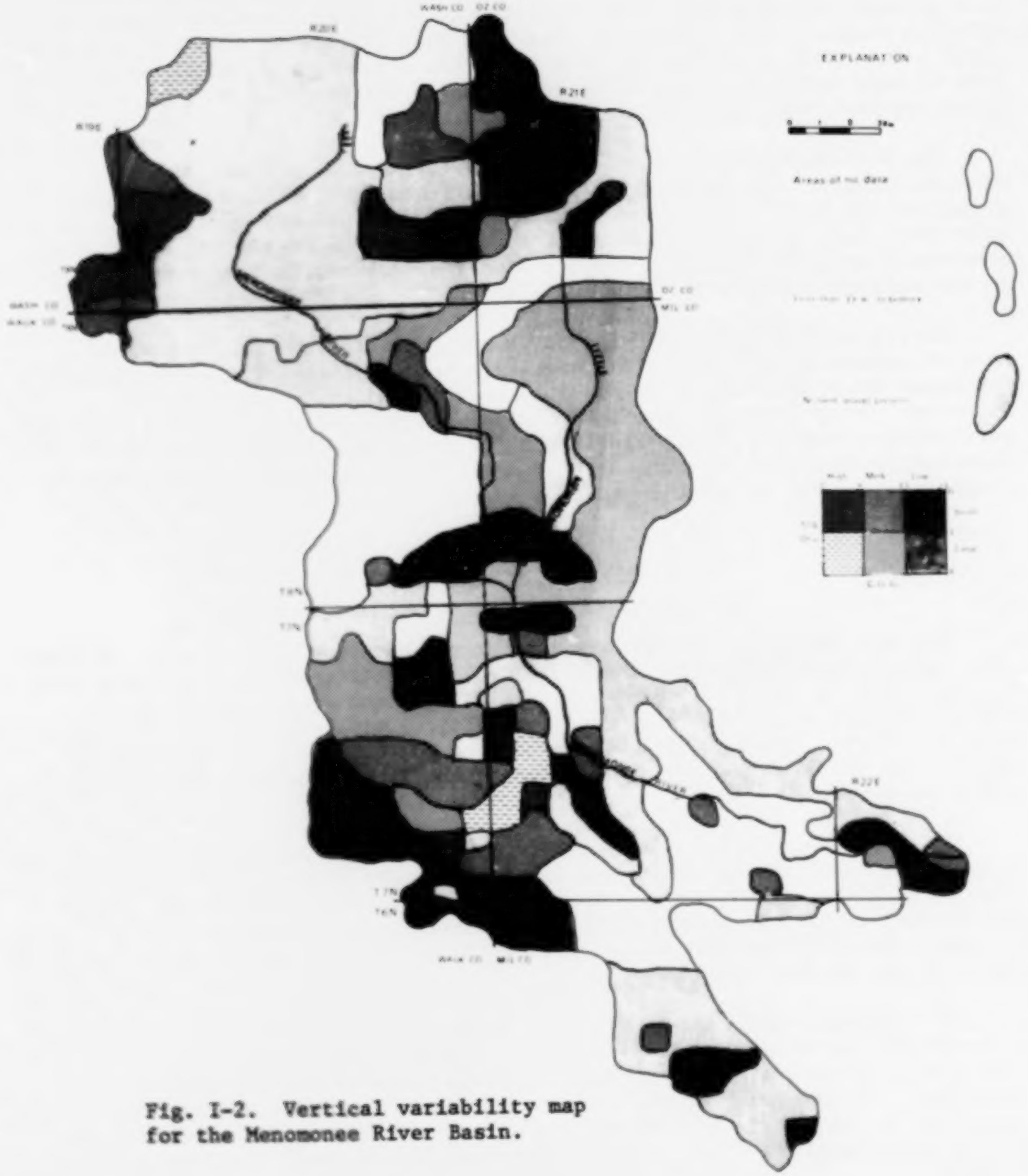

WASH CO
OZ CO
R20E
R21E
R19E
R22E
WASH CO
WAUK CO
OZ CO
MIL CO
T8N
T7N
T7N
T6N
WAUK CO
MIL CO
EXPLANATION
Areas of no data
High
Med
Low
Small
Large

Fig. I-2. Vertical variability map for the Menomonee River Basin.

7.6 to 22.9 m (25 to 75 ft) beneath the surface. The fairly linear orientation of these deposits and their proximity to the Menomonee River suggest an alluvial origin. Well borings in this area disclose a gray clay 0.9 to 1.8 m (3 to 6 ft) thick overlying the sand deposits. This clay is highly cohesive, free of sand and pebbles and tends to act as a confining bed for the underlying aquifer (Vogt, personal communication, 1976).

The most extensive sand and gravel deposit is found in T7W,R20E of Waukesha County. The deposit has a NW-SE orientation, similar to the topography of the area. In the far western portion of the Basin the deposit is relatively deep in the subsurface but tends to surface toward the east. This phenomenon occurs because the deposit is horizontal and is more deeply buried in the western upland portion of the Watershed.

Little stratigraphic information is available in the Lower Menomonee River-Milwaukee area. This area contains a major portion of the pre-glacial Menomonee River (11) and it is possible that the valley contains buried alluvium. Other portions of the Basin in which no data were available are in northwestern Waukesha County and in the far northern portion of the Basin. Surrounding materials suggest that extensive sand and gravel deposits are probably not found in these regions.

Sand and gravel map

The sand and gravel percentage map for the Watershed was constructed from data used in the compilation of the vertical variability map. The number next to each point in Fig. I-3 is the percent of sand and gravel in the 22.9 m (75 ft) section used for the vertical variability map. Contours in 20% intervals are given. Areas where depth to bedrock is < 15 m (50 ft) are included in the less than 20% areas and these points are identified by a dot without a numerical value.

The map shows that in the northern portion of the Watershed (north of the confluence of the Menomonee and Little Menomonee Rivers) over 75% of the area has < 20% sand and gravel. The few permeable units found in the region are located in upland regions which have little direct connection to the Menomonee River System indicating that little groundwater discharge to the river occurs in this region.

The deposits surrounding the Lower Menomonee River (past the confluence with the Little Menomonee River) contain thick sand and gravel deposits in the western portion of the Watershed. No significant deposits exist east of the river. It appears that the eastern portion of the Basin has little potential to contribute much groundwater to the river system. Moreover, the fine-grained material found in these deposits will attenuate most contaminant inputs.

However, potential exists for significant groundwater discharge to the river in the western portion of the Lower Menomonee River Basin. Moreover, the sand and gravel deposits in this area which occur near the surface (Fig. I-2) are susceptible to groundwater contamination. The sand and gravel

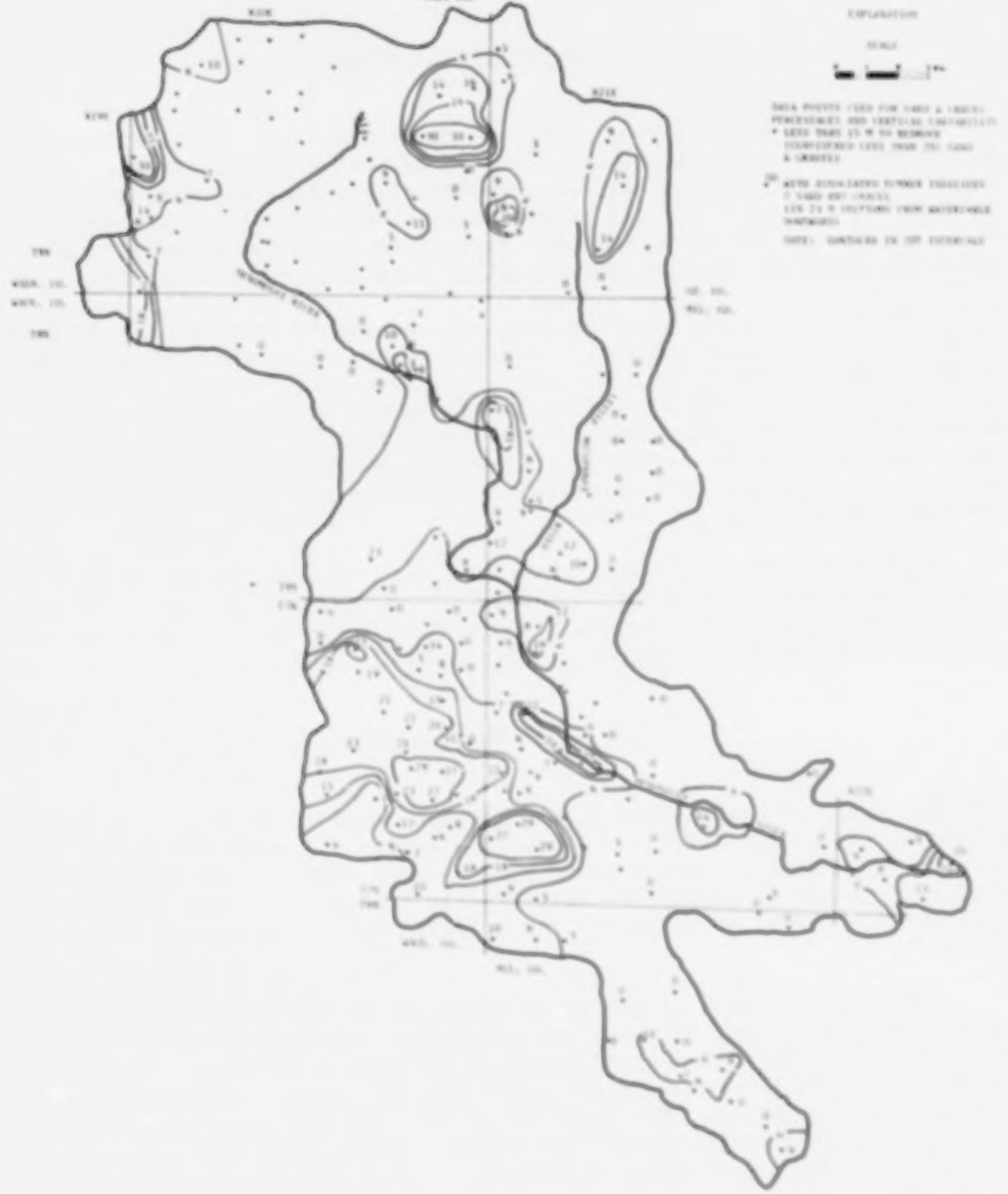

EXPLANATION
SCALE

Fig. I-3. Sand and gravel percentage map of the Menomonee River Basin.

percentages are highest in the Elm Grove area, but thin to < 20% along the Menomonee River.

Stratigraphy near the Menomonee River

Examination of well logs along the Menomonee River (12) indicates that--in the headwater area--the river flows on or near bedrock. In the middle section the river flows mainly on clay and clayey till deposits and bedrock is found up to 22.9 m (75 ft) below the riverbed. The lower section indicates that the flow of the river is again on bedrock for a few kilometers after which the riverbed is situated on shallow sand and gravel deposits.

It is important to note that the unconsolidated aquifer is fairly thin along most of the river profile. Bedrock exists at or near the surface along 29 km (18 mi) of the 45 km (28 mi) of the river that is shown in the cross section. This thinning of unconsolidated material along the river has a marked effect on the groundwater flow patterns in the sand and gravel aquifer. The effect is to produce a wedge-shaped sand and gravel aquifer where the upland recharge areas have substantially thicker glacial deposits than the discharge areas along the river.

Most of the segments along the river where bedrock is not close to the surface are underlain by lacustrine clay and clayey till and the materials are of low permeability. Therefore, the hydraulic connection between surface and groundwater along these reaches of the stream is poor.

Hydraulic conductivities

Hydraulic conductivities of the glacial material in the Basin were determined from slug tests and grain size analyses. Augered samples from 14 borings at 10 well sites and seven hand augered samples from streambed material were used in the determination of hydraulic conductivity from grain size. Slug test determinations of hydraulic conductivity were completed at seven well sites.

The procedure used to determine hydraulic conductivity from grain size analysis was developed by Masch and Denny (13). The method involved determination of the ranges, medians and standard deviations of grain sizes in a sample. The distribution about the median grain size has a major effect on the data. Samples which contain a wide range of particle sizes have a significantly smaller hydraulic conductivity than samples with a similar median grain size, but lower standard deviation and range.

The results obtained from the study are shown in Fig. I-4. Most of the samples were poorly sorted explaining the low hydraulic conductivities. The highest hydraulic conductivities were for streambed materials ranging from 1.6 to 57.0 m/d (40 to 1400 gpd/ft^2) with the average being 6.6 m/d (160 gpd/ft^2). The streambed material is fairly well sorted explaining the relatively high permeability values.

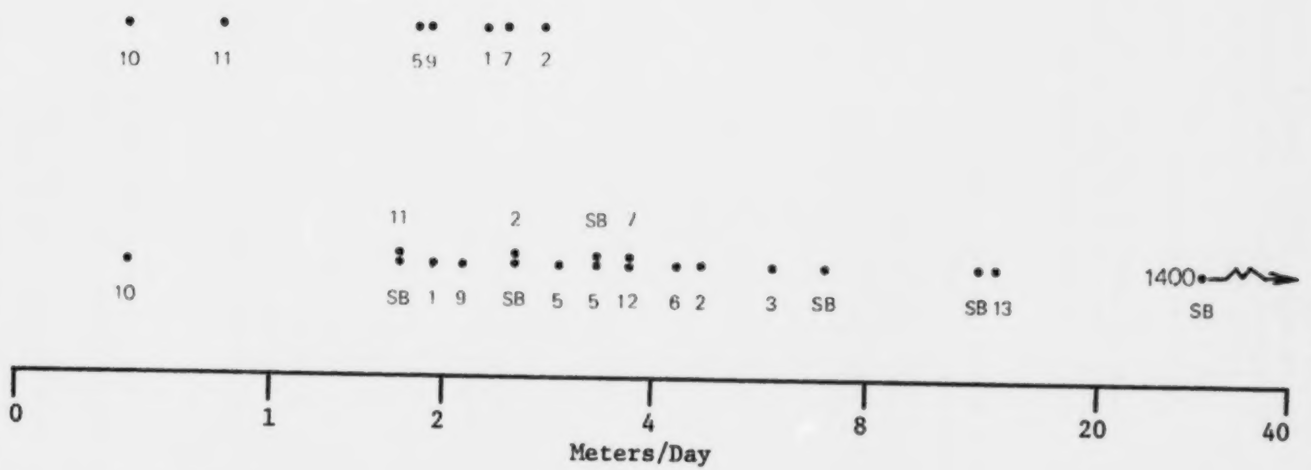


Fig. I-4. Hydraulic conductivities of the glacial deposits where SB is streambed material and numbers represent well sites.

Hydraulic conductivity estimates obtained from the sand and gravel deposits in the Basin ranged from 3.5 to 13.5 m/d (85 to 330 gpd/ft^2) with an average of 4.5 m/d (110 gpd/ft^2). Poor sorting of the deposits probably was responsible for the low values. Thick gravel units that are denoted in high capacity well logs for Waukesha County are situated deeper than the samples used in this analysis. These deep gravel layers may have much higher hydraulic conductivities, 40 to 410 m/d (10^3 to 10^4 gpd/ft^2) and substantially add to the overall permeability and water resources of Waukesha County.

The hydraulic conductivities of glacial till and clay were found to range from 0.4 to 2.7 m/d (10 to 65 gpd/ft^2) with an average value of 1.6 m/d (40 gpd/ft^2) which falls into the range expected for materials of this type (7, p. 53).

Slug tests were performed on a number of observation wells and data were analyzed by the technique of Bower and Rice (14). A slug test involves the rapid withdrawal of a slug of water and measurement of the rate of water level rise back to equilibrium. The method of analysis given by Bower and Rice (14) is designed for wells which partially penetrate the aquifer, as did all of the test wells. Water levels in wells situated in sand units rose too rapidly for measurement.

The results of the slug test analyses are shown in Fig. I-4. Values range from 0.4 to 2.7 m/d (9 to 65 gpd/ft^2). Most results correlate well with results obtained from grain size analysis.

Summary of hydrostratigraphic units

For the purposes of this study, the Watershed was divided into five sections of similar hydrostratigraphy, i.e., in each section the shallow aquifer is of similar thickness and hydraulic conductivity (Fig. I-5).

The far northwestern part of the Watershed, centered around the Menomonee River north of W6 at Pilgrim Road, is an area of shallow bedrock covered by a thin veneer of glacial till. The Menomonee River flows almost exclusively on bedrock. The sand and gravel aquifer in this area is virtually nonexistent and groundwater seepage rates are controlled by the hydraulic properties of the bedrock. Because of the shallow bedrock in this area it was impossible to install observation wells and few water table data were taken.

The Little Menomonee River watershed contains few sand and gravel deposits. Most of the area is overlain by clay and clayey till deposits. Shallow bedrock occurs in the headwaters and near the mouth of the Little Menomonee River. The average hydraulic conductivity for the area is about 1.6 m/d (40 gpd/ft^2).

Surrounding the next reach of the Menomonee River, from W6 at Pilgrim Road to W1 at 124th Street in Butler, the glacial aquifer consists of material of relatively low hydraulic conductivity with somewhat extensive sand and gravel lenses buried beneath the river for approximately two-thirds of the reach. The glacial aquifer is substantially thicker along the river, but lacustrian clays and clayey tills which overlie the sand deposits result in poor hydraulic

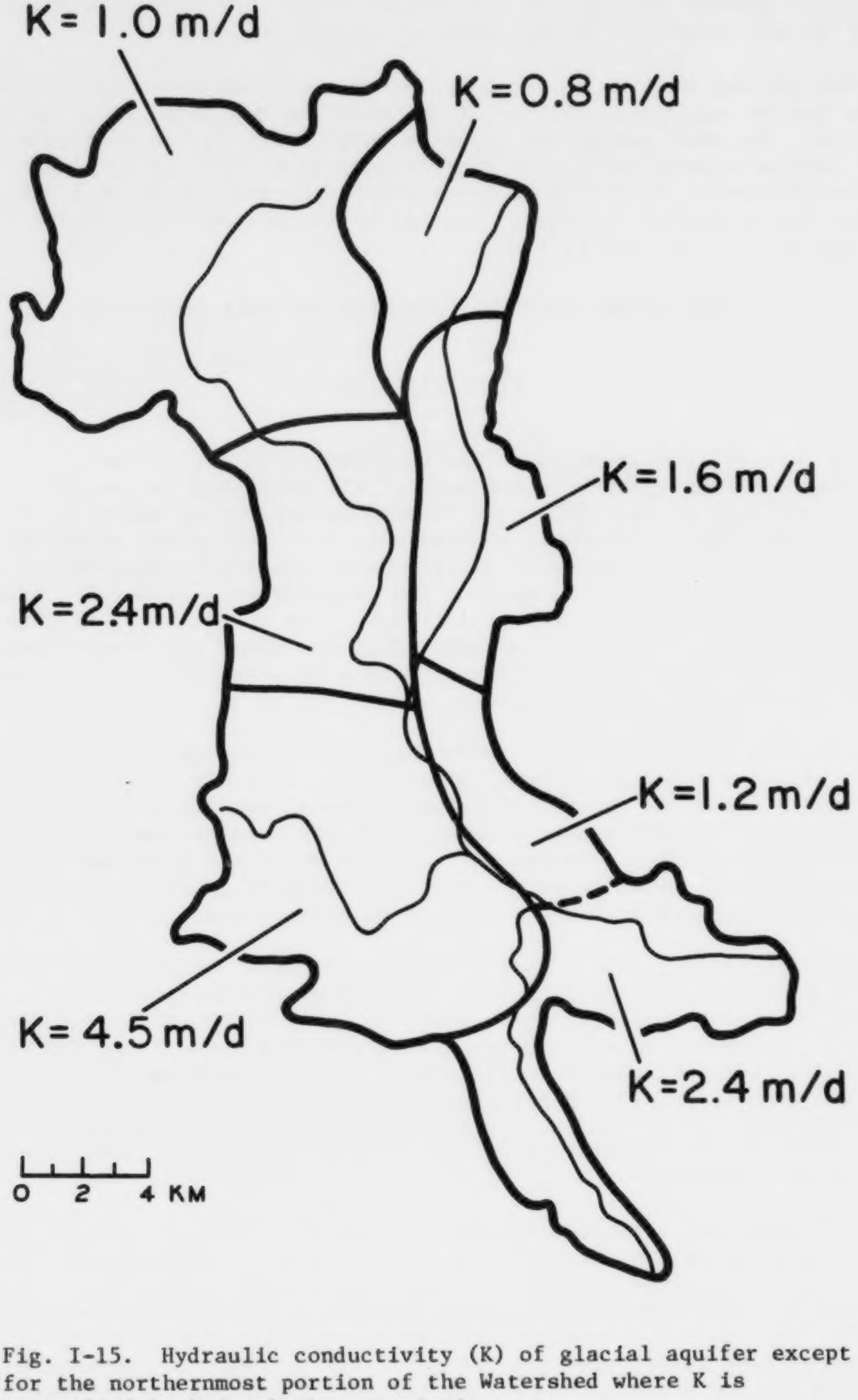

K= 1.0 m/d
K=0.8 m/d
K=1.6 m/d
K=2.4m/d
K=1.2 m/d
K= 4.5 m/d
K=2.4 m/d
0 2 4 KM

Fig. I-15. Hydraulic conductivity (K) of glacial aquifer except for the northernmost portion of the Watershed where K is controlled by bedrock characteristics.

connection between groundwater and surface flow. The average hydraulic conductivity of the materials in this area is 2.5 m/d (60 gpd/ft^2).

The glacial aquifer in the Lower Menomonee River Basin downstream of Butler can be separated into two areas, with the Menomonee River as the dividing line. The sand and gravel deposits which exist on the west side of the river have an average hydraulic conductivity of 4.5 m/d (110 gpd/ft^2). The eastern portion of the Basin contains thick clay and clayey till deposits with no sand and/or gravel deposits. Average hydraulic conductivities for this area are 1.2 m/d (30 gpd/ft^2).

Procedures for Site Selection and Data Collection

Observation wells

In July of 1976, permission was obtained to install observation wells at 16 sites in the Watershed. Since much of the Watershed is residential and/or industrial, most of the sites were located in village or county parks. Wherever possible, well sites were located near U.S. Geological Survey-Wisconsin Department of Natural Resources surface water monitoring stations to allow comparison of the quality of surface and groundwater. In August 1976, 38 observation wells were drilled at 14 sites. Two of the proposed sites were abandoned because of shallow bedrock. Fig. I-6 shows the general location of well sites and the number of wells at each site. Appendix I-A-1 contains the street locations of the well sites.

Thirteen of the well sites were located in recharge (upland) areas or along tributary streams and were selected for the study of groundwater flow patterns in the Basin and for the study of water quality of the upland areas. Twenty-five of the wells were located along the main reaches of the Menomonee and Little Menomonee Rivers and were used to study the groundwater quality from recharge to discharge areas. Wherever possible, piezometer nests were installed on each side of the river and in upland areas.

Four of the well sites were located in areas where it was suspected that surface water was infiltrating into the groundwater as identified by cones of depression near the river. These sites (W1, W6, W8 and W13) were used to identify the nature of surface contaminants moving into the groundwater and to measure rates of induced infiltration. Two of the sites (W1 and W6) were equipped with Leopold and Stevens water-level recorders and Peabody and Ryan thermographs. The continuous monitoring instruments were installed to record short term changes in water levels and temperatures to estimate rates of induced infiltration.

The observation wells used were 3.18 cm (1.25 in) in diameter and finished with plastic well points 30 cm (1 ft) in length. Approximately half of the wells were constructed of polyvinyl chloride plastic pipe and the remainder were constructed of galvanized pipe. Shallow wells were located approximately 2 m (6.5 ft) beneath the water table and varied from 2.8 to 9.5 m (9 to 31 ft) in length; deep wells were up to 16 m (52 ft) in length. Appendix I-A lists the location and depth of the wells, the well logs, and the general land use surrounding each site.

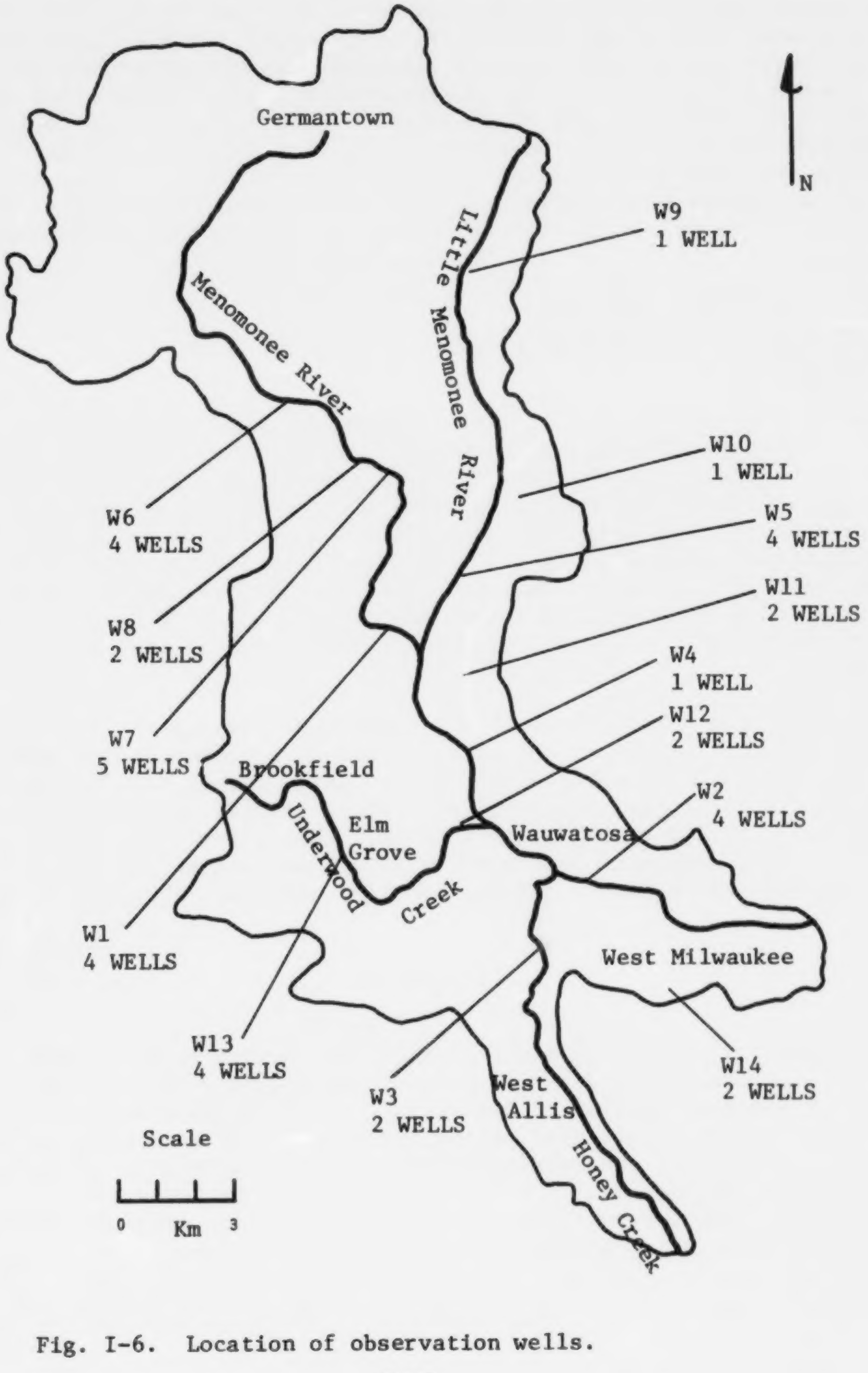

Germantown
N
W9
1 WELL
Menomonee River
Little Menomonee River
W10
1 WELL
W6
4 WELLS
W5
4 WELLS
W11
2 WELLS
W8
2 WELLS
W4
1 WELL
W12
2 WELLS
W7
5 WELLS
Brookfield
Elm Grove
Underwood Creek
Wauwatosa
W2
4 WELLS
W1
4 WELLS
West Milwaukee
W13
4 WELLS
W3
2 WELLS
West Allis
W14
2 WELLS
Honey Creek
Scale
0
Km
3

Fig. I-6. Location of observation wells.

Monitoring schedule

Due to time and other constraints it was considered optimum for groundwater levels and water quality samples to be obtained monthly for 13 months, from September 1976 to September 1977. Because of uncontrollable scheduling problems water quality samples were analyzed for only 10 monthly periods. The 13 month period of time was considered the minimum length that could reasonably be used to assess the seasonal variation in quality of the shallow groundwater and to analyze the interactions of groundwater and surface water. It should be recognized that the 1 year study only offers the opportunity for a relatively short term analysis of the shallow groundwater system and may result in biases due to short term changes in climate and current land use practices.

Sample collection and preparation

Water samples obtained from the observation wells were removed by bailing or by lowering tygon tubing into the well and applying a vacuum. The vacuum supplied for the system was produced by a bicycle pump with an inverted diaphragm. Although the method does not allow water to be pumped at the rate of a conventional pump, it does enable the collection of water samples that are relatively undisturbed in the sense that they are not exposed to oxygen. Contact with the atmosphere also may cause a change in concentration of such dissolved gases as ammonia or carbon dioxide. Thus, this vacuum system offered the best method of obtaining a sample exhibiting the true properties of the groundwater.

Samples were kept chilled at all times and were filtered within 24 hr after sampling. Because of the large amount of sediment in the samples, the water was filtered with Whatman 42 filter paper, rather than Millipore filters. Water samples for toxic metal analysis were acidified to pH 1 with nitric acid, and stored in acid washed plastic bottles. Analyses of the nutrients and alkalinity were completed within 48 hr after sampling and analysis of the major cations was performed for two sampling periods.

Parameters

The physical, chemical and biological parameters measured are listed in Table I-1. The major cations and anions were analyzed to characterize the general groundwater quality in the Basin. Nutrients were analyzed to identify the effects of fertilizer application and septic tank effluent on groundwater quality. Toxic metal concentrations were measured to detect any deterioration of groundwater quality caused by industrial discharges or automobile exhausts. Bacterial analyses were performed to identify any biological contamination in the shallow groundwater system.

Table I-1. Water quality parameters*

Parameters

Chemical

Specific conductance (11)** Total dissolved solids (8) pH (11)
Calcium (2) Magnesium (2) Sodium (2) Potassium (2) Chloride (9)
Sulfate (9) Nitrate (9) Ammonia (9) Total dissolved phosphate (9)
Alkalinity (9) Lead (2) Copper (2) Zinc (2) Cadmium (2)

Physical

Temperature (12)* Water level (12)*

Biological

Total coliforms (2) Fecal coliform (1) Fecal streptococci (1)

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*Numbers in parentheses indicate number of months for which data are available.

**Signifies on-site measurements.

I-4. RESULTS AND DISCUSSION

Groundwater-Surface Water Relationships

Groundwater flow patterns

According to Toth (15), groundwater flow systems can be divided ideally into three types: local, intermediate and regional. A local flow system has its recharge area in a topographic high and its discharge area in an adjacent topographic low. The intermediate flow system is viewed as having recharge and discharge areas that are not in adjacent topographic highs and lows. The discharge area for an intermediate flow system may be in a topographic low which is several sub-basins down gradient from its principal recharge area. A groundwater system which is considered regional has its recharge area in the regional topographic high, while its discharge area occupies the topographic low for the basin. Fig. I-7 shows theoretical local, intermediate and regional flow systems.

Toth (15) viewed these flow systems as having well-defined boundaries that theoretically identify changes in flow patterns, water quality and relative rate of groundwater movement. In a basin with only one aquifer medium, a local flow system would have a higher recharge rate than the regional flow system. The flow paths of the groundwater in a local flow system also would be shorter and steeper than in a regional system. Ideally this would produce faster movement of groundwater in a local flow system, with water quality that is quite different from that in the regional system. In regional flow systems groundwater moves slower and over a longer path length. Thus, groundwater moving through a regional flow system typically has higher concentrations of dissolved ions (16), than groundwater moving through a local flow system.

The depths at which the boundaries between flow systems develop are dependent upon a number of geomorphological factors. The computer simulations of Toth (15) indicate the development, in intensity and depth of local flow systems to be related directly to increased local topographic relief and related inversely to increased regional slope. Strong regional flow systems developed where local relief was negligible and where the ratio of total aquifer thickness to local relief was high. A weak local flow system will have only a portion of the total aquifer contributing discharge to that sub-basin. Moreover, a strong local flow system has most or all of the aquifer discharging into that sub-basin.

The Toth (15) hypothesis of flow systems can be used to describe the groundwater flow patterns for southeastern Wisconsin. The regional groundwater

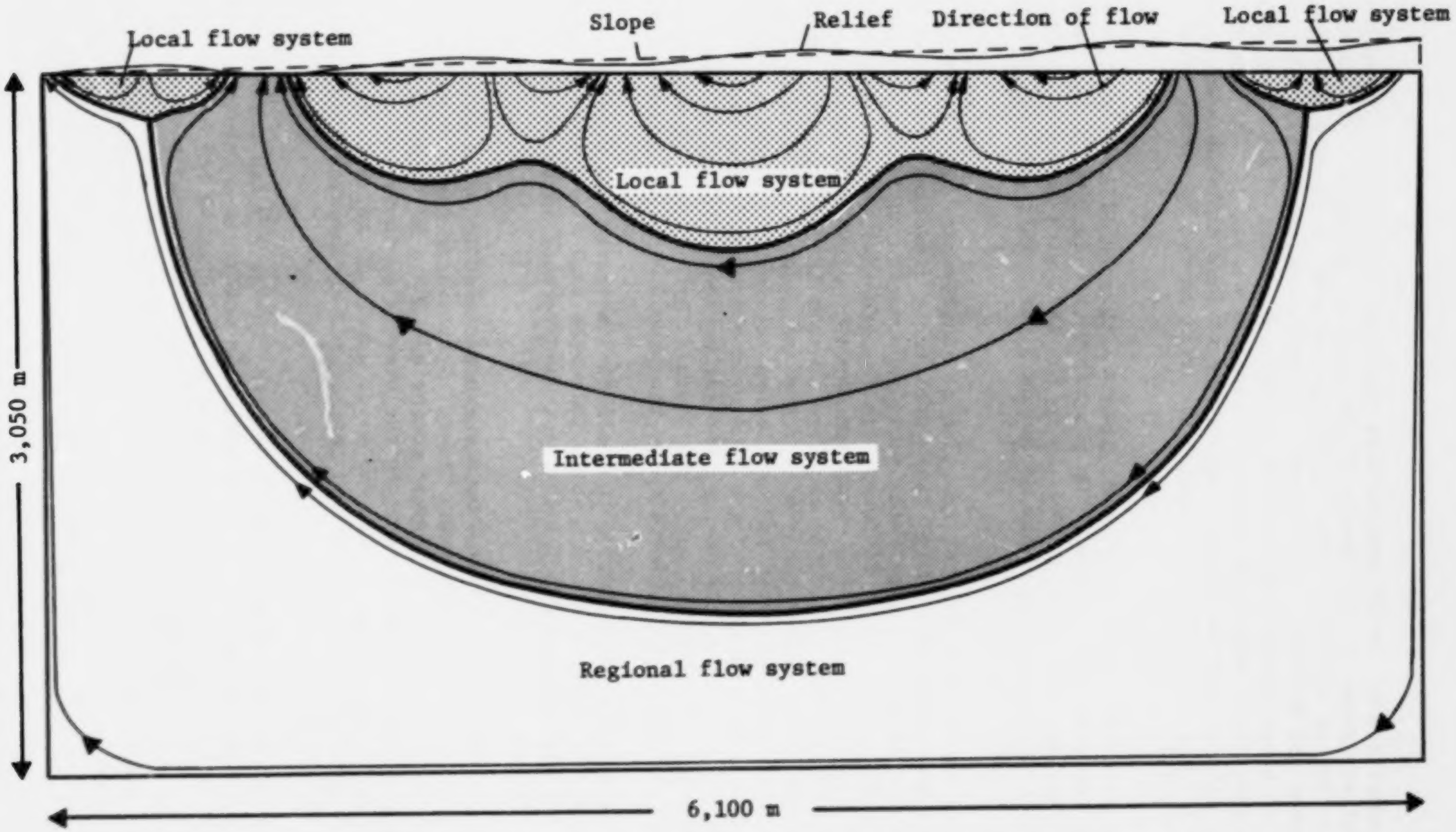
Local flow system
Slope
Relief
Direction of flow
Local flow system
Local flow system
Intermediate flow system
Regional flow system
3,050 m
6,100 m

Fig. I-7. Theoretical patterns for local, intermediate and regional flow systems. Adapted from Toth (15).

system is comprised of the Wisconsin-Lake Michigan Basin (17). The major shallow aquifer system in this basin is the Niagara dolomite. The general groundwater flow is eastward. The region is composed of three sub-basins: Fox, Menomonee and Milwaukee Watersheds. As mentioned previously, the topography of these Basins reflects the effects of recent glaciation, which produced upland areas comprised mostly of morainal deposits. The regional topographic slope, from the Niagara escarpment to Lake Michigan averages 6% (17). The average slope of the morainal deposits in the Menomonee River Basin is < 5% (1).

As the Toth (15) model predicted, a basin with subdued local relief produced a strong regional flow system. The potentiometric surface in the Niagara dolomite shows that the regional flow is to the east with almost no inflection of groundwater movement towards the Menomonee River. This pattern differs from that of the local flow system.

Seasonal water table maps of the glacial aquifer are shown in Figs. I-8 to I-10. The maps were constructed from water table elevations measured in the observation wells and other water table information obtained from the U.S. Geological Survey. One major difference in the groundwater flow patterns in the glacial aquifer system is the westward movement of the groundwater in the eastern half of the Basin. In the recharge area in the eastern part of the Menomonee River Basin, water table elevations are 8 to 12 m (26 to 40 ft) higher than elevations measured in the Niagara aquifer. Another difference is the strong southern inflection of groundwater movement near the Menomonee River in the lower half of the Basin. The inflection is caused by the slope of the river channel averaging 6% while the Basin's flanks slope at approximately 5%, therefore adding a third dimension to the movement of the groundwater.

While water table information in the Basin indicates the development of a local flow system, further investigation indicates that the system is confined largely to the glacial aquifer and does not involve much interaction with the Niagara dolomite.

Negligible vertical gradients were measured in nested piezometers along discharge reaches near the Menomonee River. Groundwater temperatures in these wells were 3° to 5° C warmer in summer months and 2° to 3° C colder in winter months than groundwater temperatures in the Niagara as indicated on U.S. Geological Survey well longs. Thus, no major upwelling of water from the underlying Niagara dolomite occurs and most of the groundwater flows horizontally into the river.

Observation wells (sites 3 and 13) located in the glacial aquifer of upland areas and near large cones of depression in the Niagara dolomite were found to have water level elevations of 9 to 12 m (30 to 40 ft) higher than in the dolomite. Measurements of heads in nested piezometers at these sites indicated that the cones of depression had only a minor effect on the local flow system, indicating that a rather poor hydraulic connection exists between the two aquifers.

The local flow system in the Menomonee River Basin is viewed as being semi-wedge shaped. The maximum height of the wedge is taken to be the vertical thickness of the saturated aquifer at the basin boundaries down to the river

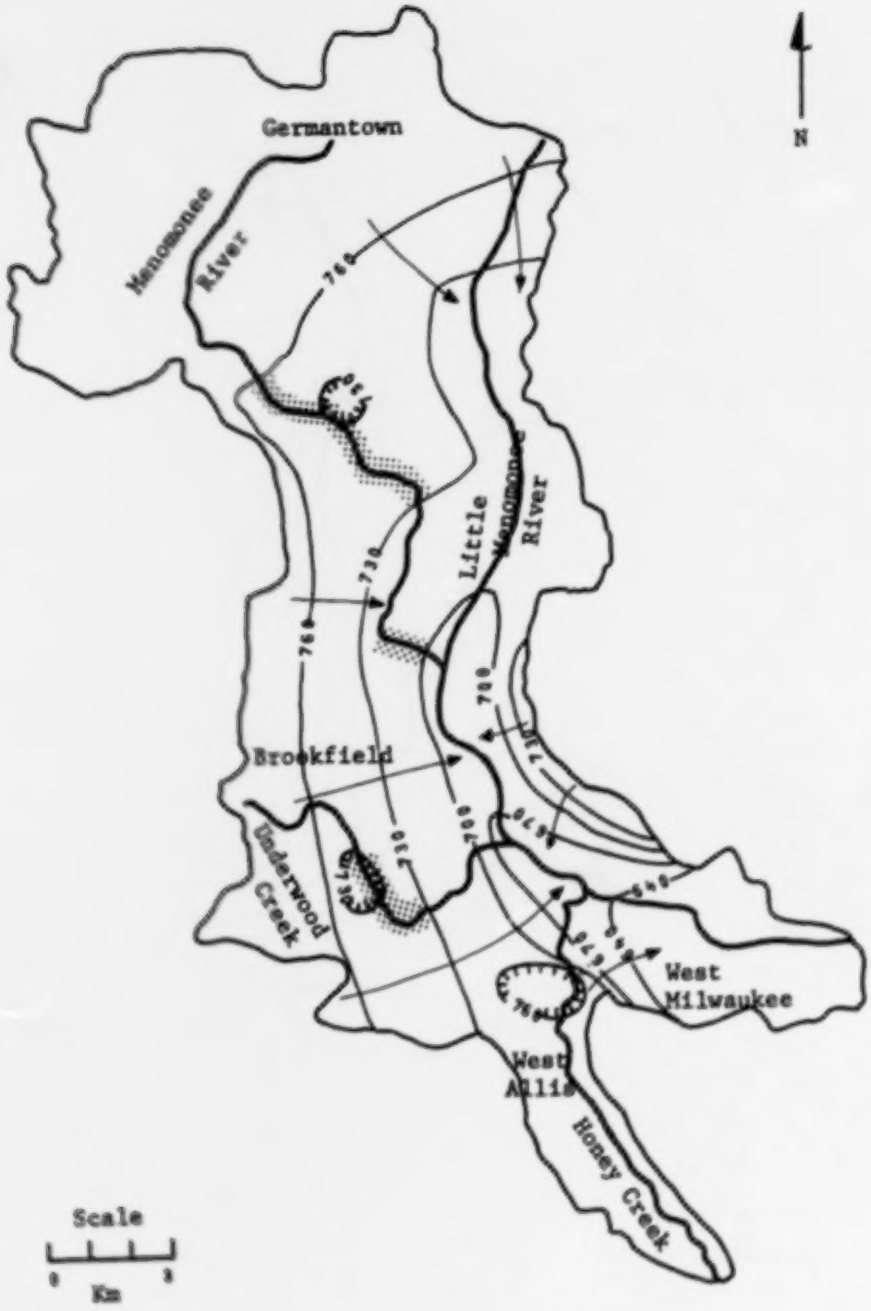
N
Germantown
Menomonee River
760
730
Little Menomonee River
760
730
700
Brookfield
670
640
Underwood Creek
West Milwaukee
West Allis
Honey Creek
Scale
0
3
Km

Fig. I-8. Watertable of glacial aquifer — Fall 1976. Shaded areas represent losing reaches of Menomonee River System.

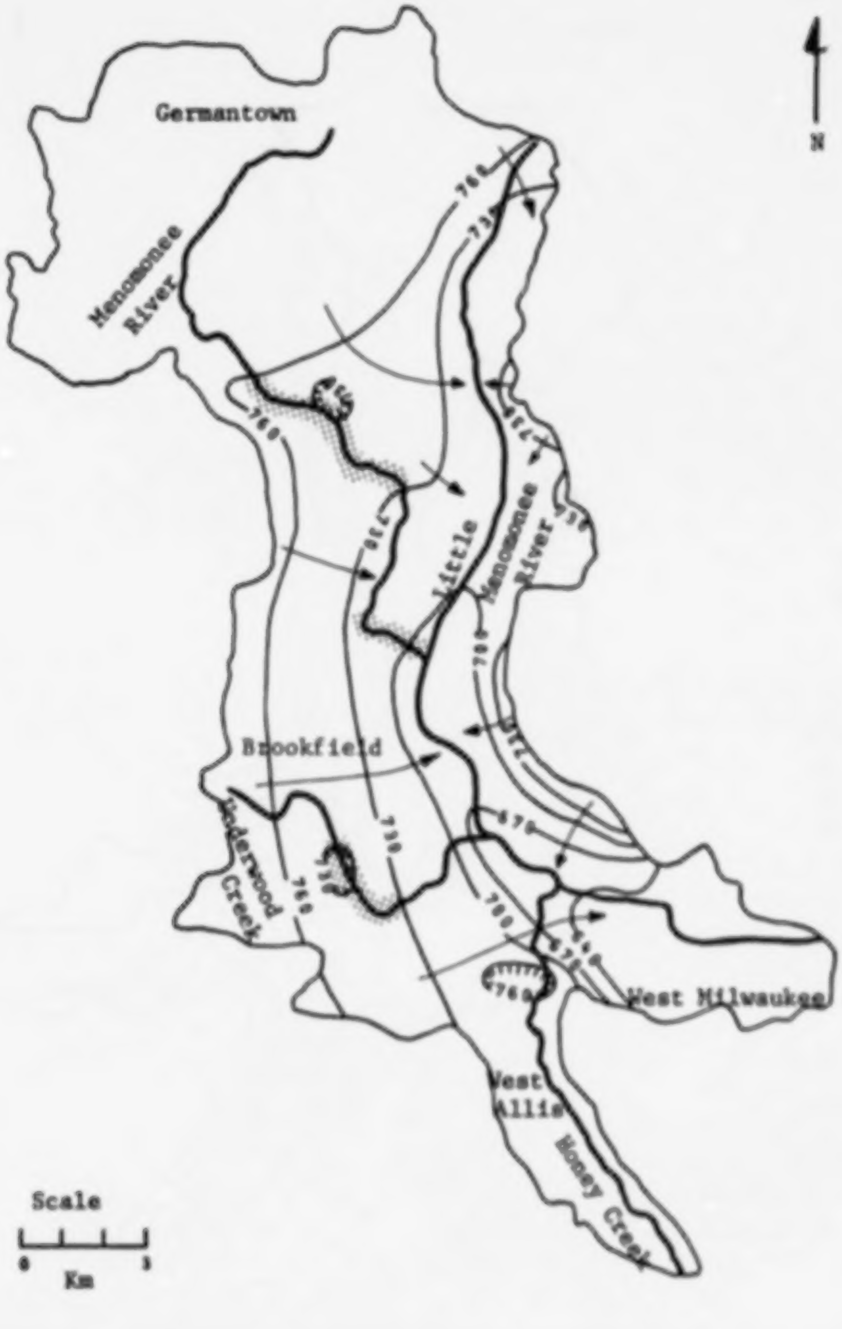
Germantown
Menomonee River
Little Menomonee River
Brookfield
Underwood Creek
West Milwaukee
West Allis
Honey Creek
760
730
700
670
640
N
Scale
0
3
Km

Fig. I-9. Watertable map of glacial aquifer — Winter 1976-77. Shaded areas represent losing reaches of Menomonee River System.

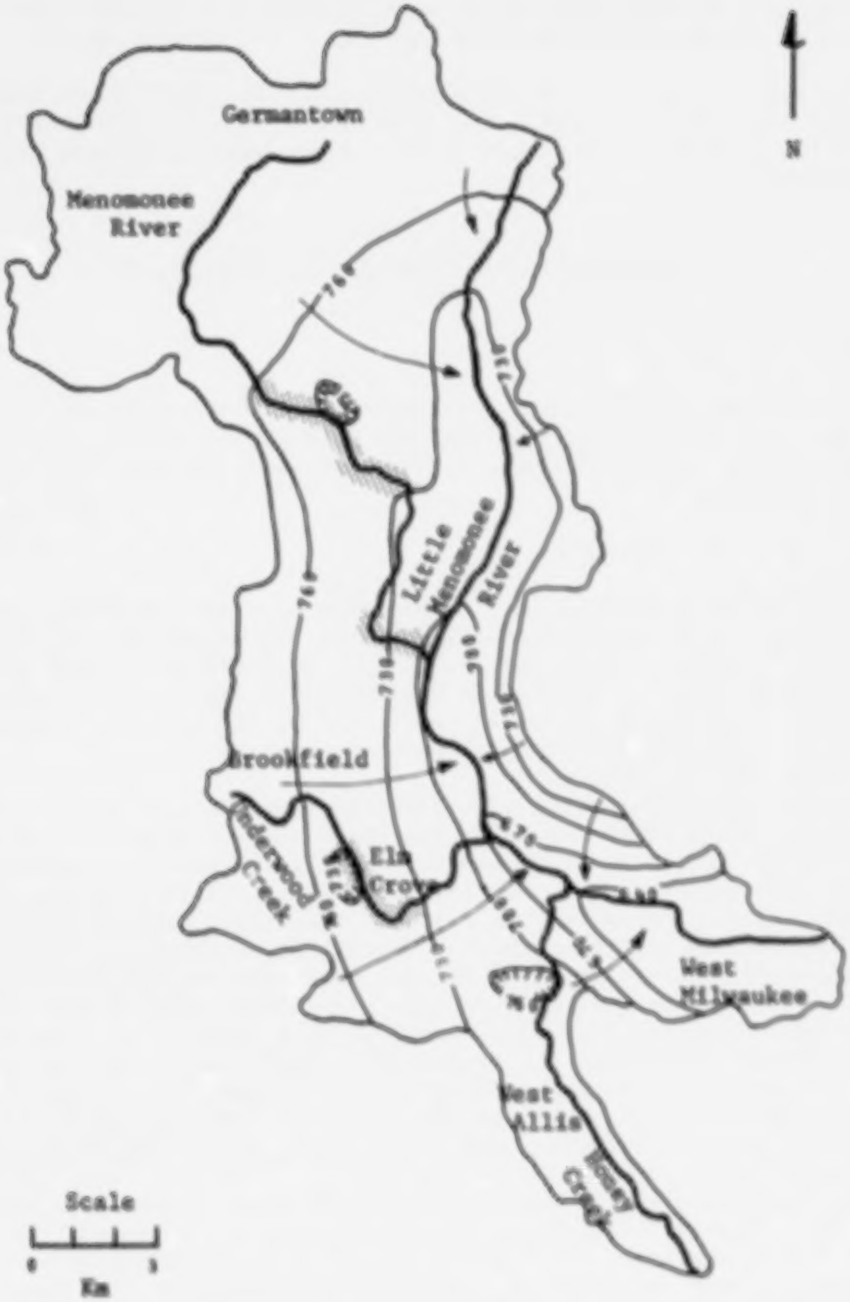
N
Germantown
Menomonee River
760
Little Menomonee River
760
750
Brookfield
770
Underwood Creek
Elm Grove
West Milwaukee
West Allis
Honey Creek
Scale
Km

Fig. I-10. Watertable map of glacial aquifer — Spring 1977. Shaded areas represent losing reaches of Menomonee River System.

elevation. The effect is most pronounced in the southern half of the watershed, as shown in Fig. I-11, where glacial deposits are thickest in the upland areas and thin rapidly towards the river. This flow pattern agrees with the findings of Freeze and Witherspoon (18) for a two aquifer system.

The northern portion of the Watershed has less relief and generally shallower bedrock. Therefore, the groundwater flow pattern generally follows that of the regional flow system and the groundwater discharge into the river is decreased.

Groundwater discharge to Menomonee River

Methods

Groundwater discharge into the Menomonee River System was calculated in two ways. The first method involved the subtraction of all major wastewater discharge from stream discharges during non-event periods. The second method used Darcy's Law:

$$Q = K(\Delta H/\Delta l)A$$

where Q is defined as the discharge of water occurring across a cross-section of aquifer (A), in gallons per day (gpd), or cubic meters per day (m^3/d), K is hydraulic conductivity in units of gpd/ft^2 or m/d; $\Delta h/\Delta l$ is the hydraulic gradient, A is the cross-sectional area of the aquifer, perpendicular to the flow through which Q is measured.

Surface water discharges were obtained from the U.S. Geological Survey. The reaches of the Menomonee River for which surface flows were measured are: a. Germantown (Hwy F) to Menomonee Falls (Pilgrim Road); b. Menomonee Falls to Butler (124th Street); c. Butler to Wauwatosa (70th Street). Flow measurements were also obtained for one reach of the Little Menomonee River, from Donges Bay Road to Appleton Avenue. Wastewater discharge rates were obtained from the Wisconsin Department of Natural Resources and the Municipalities of Germantown, Menomonee Falls and Butler. The subtraction of wastewater discharges from non-event surface flow allows an estimation of true base flow, or the groundwater input into the river. This technique offers the most accurate way to estimate the groundwater component of stream flow. Stage-discharge relationships for some reaches of the Menomonee River System have been developed for over 10 years and non-event discharges are measured accurately.

The estimation of the groundwater component of stream flow using Darcy's Law is less accurate because of the general lack of homogeneity of the aquifer and the relatively short time period for which the groundwater-surface water relationships were investigated. While the technique is less quantitative it provides a better understanding of the groundwater flow paths and relationships between land use and quality of groundwater discharged into the river system. Test wells in a specified locality give a better indication of groundwater quality than adjacent surface waters, since industrial and municipal discharges alter quality of the true baseflow.

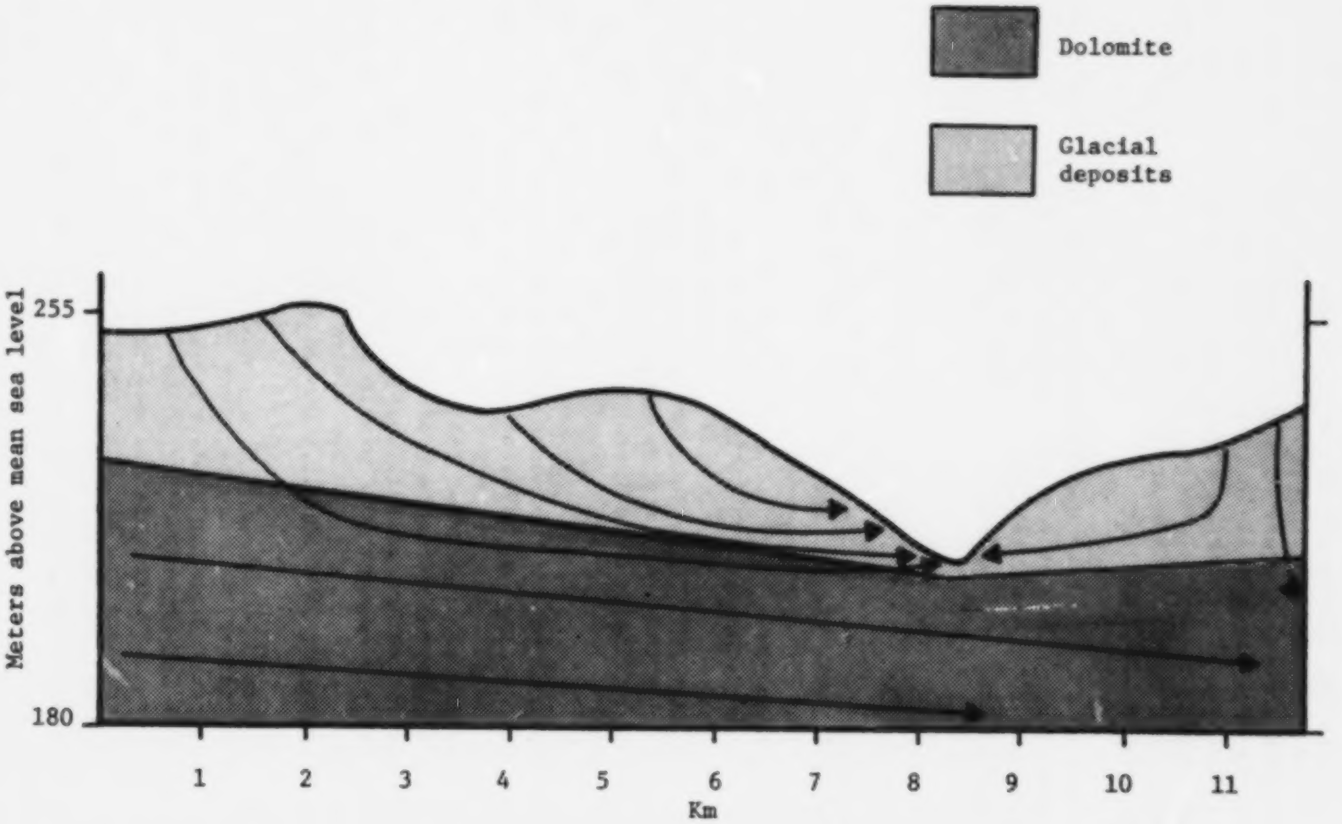
Dolomite
Glacial deposits
Meters above mean sea level
255
180
1
2
3
4
5
6
7
8
9
10
11
Km

Fig. I-11. Cross section of the southern portion of Basin showing generalized groundwater flow patterns for the local flow system.

Using Darcy's Law, the groundwater discharge to the Menomonee River System was estimated for the same reaches as the first method. The hydraulic gradients ($\Delta h/\Delta l$) were estimated from the slope of the water table between the selected reaches of the Menomonee River as shown in Figs. I-8 to I-10. The hydraulic conductivity (K) of the glacial aquifer was determined from slug tests and grain-size analyses. Extrapolation of permeability for surrounding areas was facilitated through the use of the Sand and Gravel Percentage and Vertical Variability Maps for the Basin (Figs. I-2 and I-3). The cross-sectional area (A) of aquifer contributing to stream discharge was determined by computing the average thickness of the saturated glacial aquifer wedge between the respective reaches of the stream multiplied by the length of the reach receiving groundwater discharge.

All discharges to the river were considered to arise from lateral movement of the groundwater; underflow was assumed to be negligible. Rates of surface water movement to groundwater for losing reaches of the river system were estimated using other methods which are discussed later.

Results

Seasonal estimates of groundwater discharge to the river system are shown in Figs. I-12 to I-15. The figures compare groundwater input to average seasonal non-event flow for the Menomonee River. The figures also show relative increases of groundwater and non-event surface water discharges for selected reaches of the Menomonee and Little Menomonee Rivers. The groundwater discharge rates are averages of two methods. In most cases the two methods produced variability of < 20%. Calculated results for each analysis are shown in Table I-2. Because of the inability to obtain groundwater data for the Menomonee River below 70th St., no estimates of groundwater discharges were obtained for this area.

Groundwater discharge to the Menomonee River System accounted for 50% of the non-event flow for the fall of 1976, 65% of the non-event flow during the winter of 1976-1977, 45% of the non-event flow for the spring of 1977 and 55% of the non-event flow for the summer of 1977. While spring groundwater discharges comprise the lowest percentage of stream base flow, the rate of groundwater discharge for spring of 1977, was almost twice as high as any other season. The daily discharge rate was 26,000 m^3/d (6.9 mgd) during the fall of 1976, 16,250 m^3/d (4.3 mgd) for the winter of 1976-1977, 53,000 m^3/d (14.0 mgd) for the spring of 1977 and 41,600 m^3/d (11.0 mgd) for the summer of 1977.

The largest groundwater input to the river system occurs along the Lower Menomonee River. The reach from the confluence of the Menomonee and Little Menomonee River to 70th St. accounted for 50 to 65% of the total groundwater contribution to the river. This region of the Watershed was found to have the steepest water table gradients and the most permeable aquifer material explaining the large increase in groundwater discharge shown on Figs. I-12 to I-15. The smallest input rate occurred along the reach of the Menomonee River between Pilgrim Road and Butler. Approximately 5 km of this 8.9 km reach of river was losing water to the groundwater system. This reach of stream receives discharges from two municipal wastewater treatment plants accounting

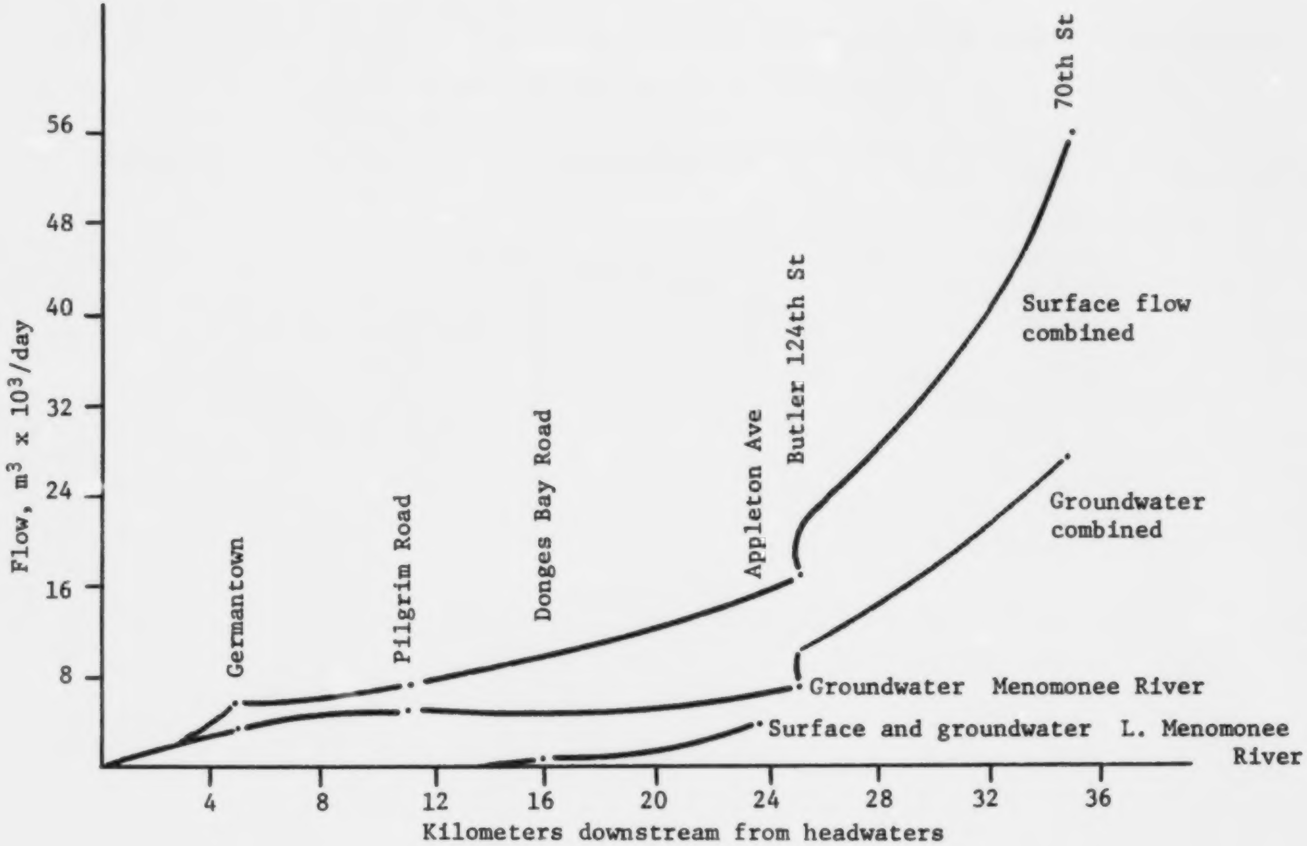

Fig. I-12. Comparison of groundwater discharge to Menomonee River System with non-event flow of the River - Fall 1976.

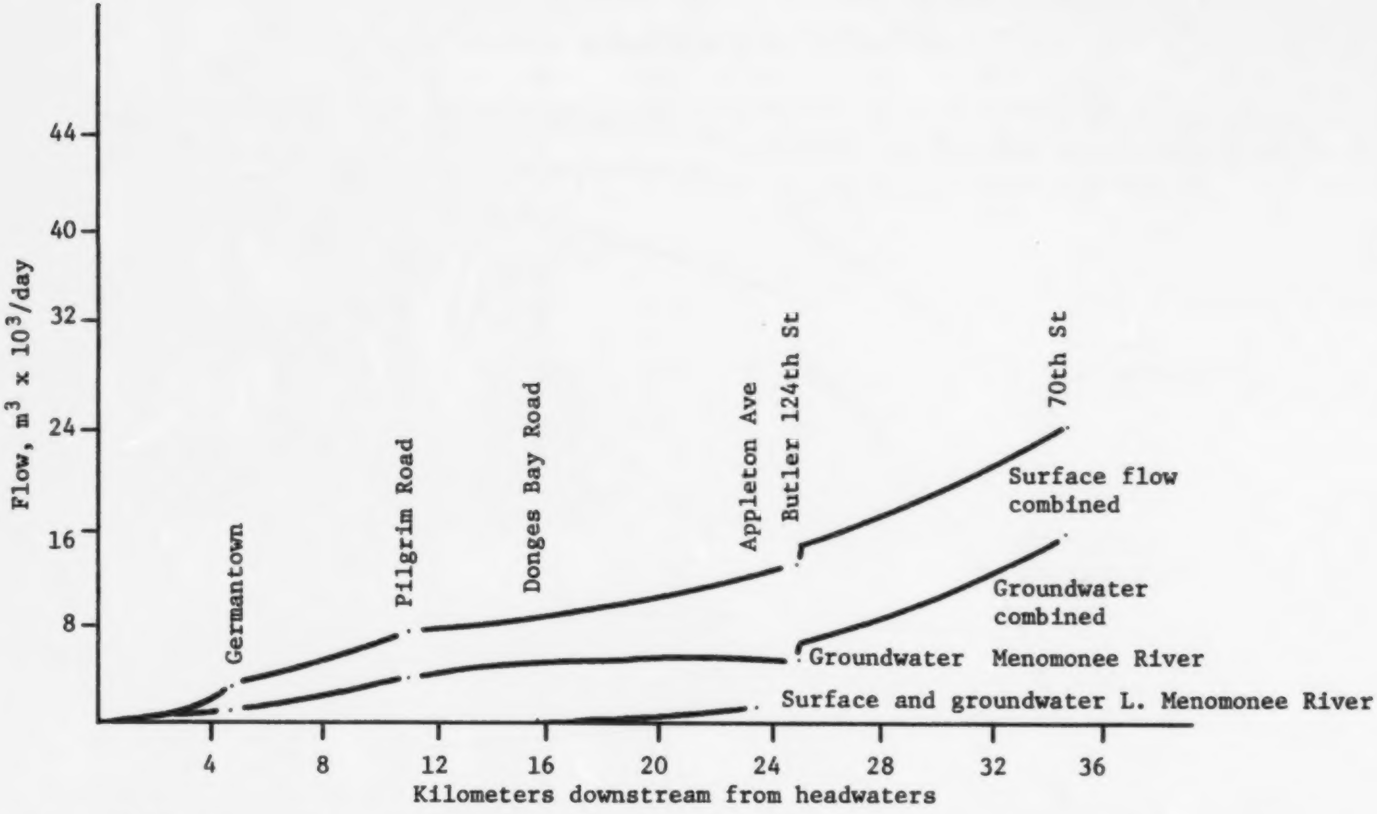

Fig. I-13. Comparison of groundwater discharge to Menomonee River System with non-event flow of the River - Winter 1976-77.

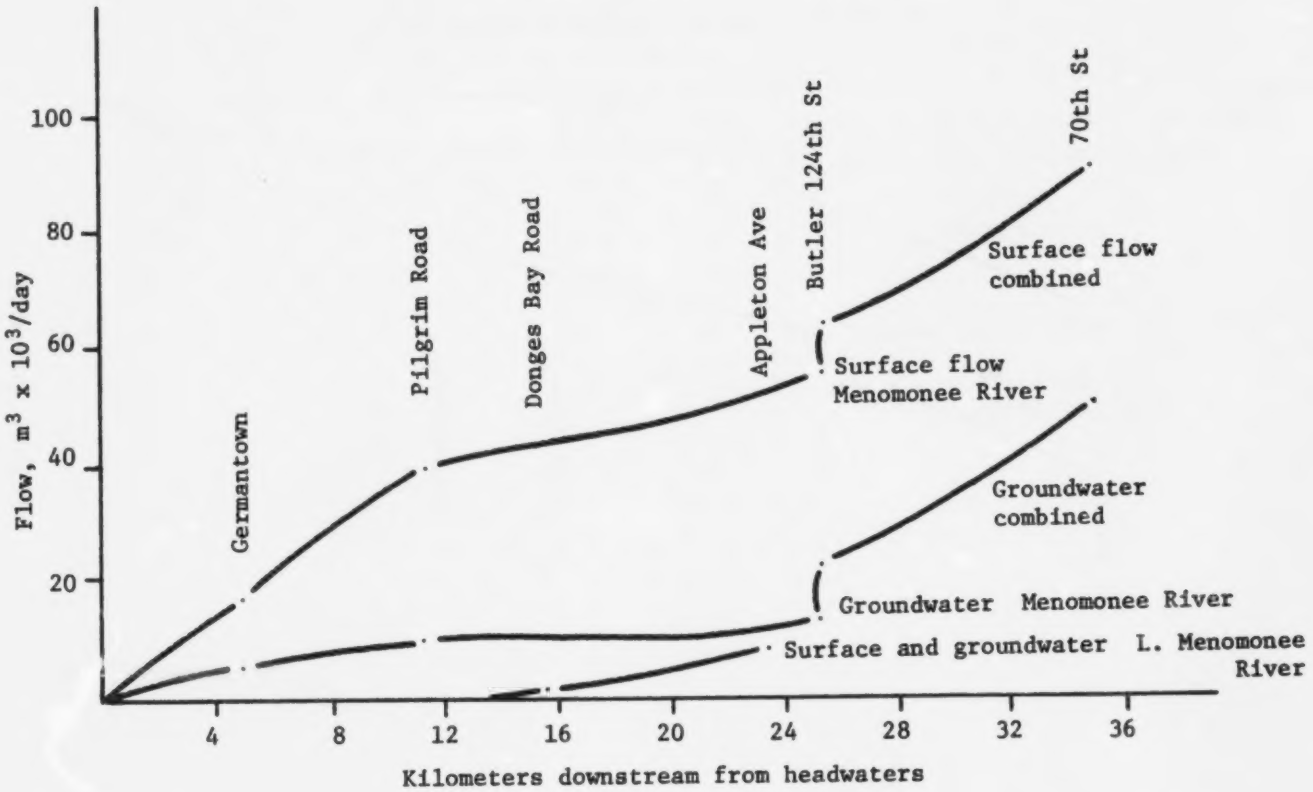

Fig. I-14. Comparison of groundwater discharge to Menomonee River System to non-event flow of the River - Spring 1977.

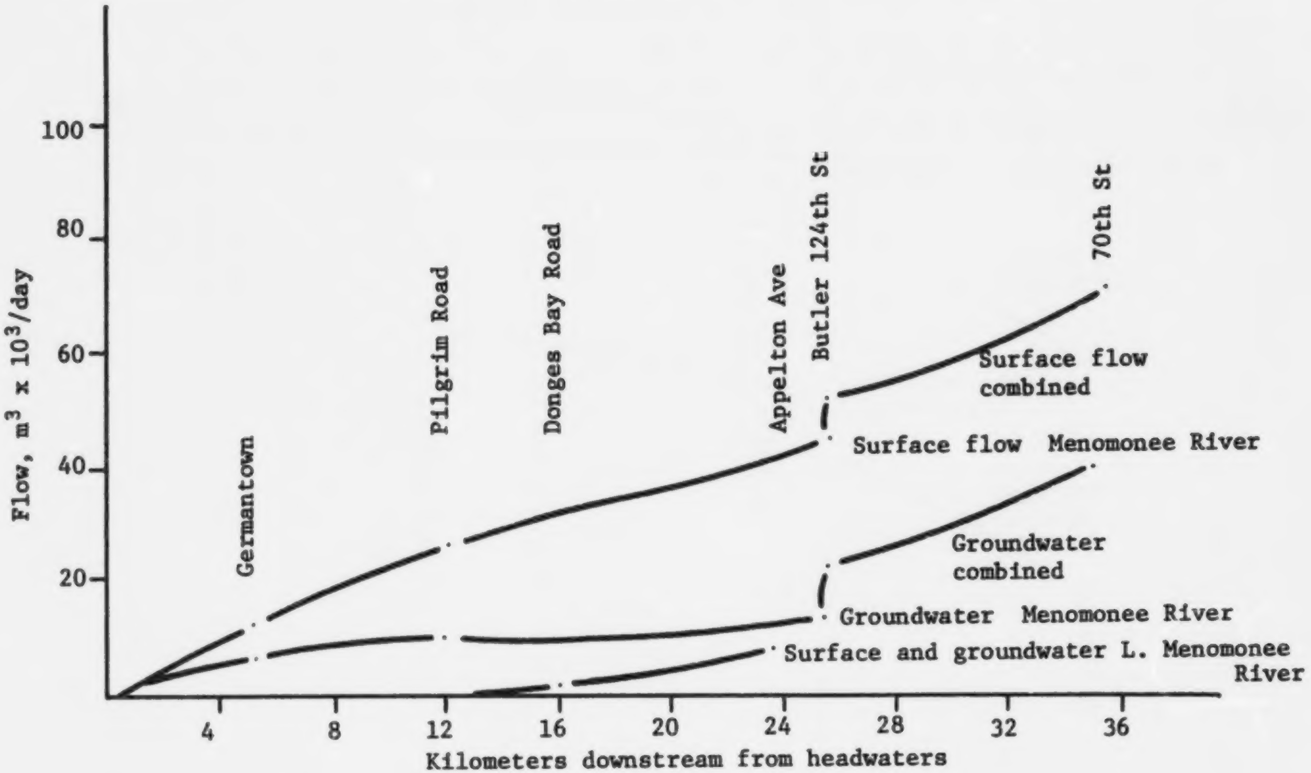

Fig. I-15. Comparison of groundwater discharge to Menomonee River System to non-event flow of the River - Summer 1977.

Table I-2. Summary of calculations of groundwater discharge to the Menomonee River System (m^3/d)

	Fall 1976		Winter 1976/77		Spring 1977	Summer 1977	
Reach	A	B	A	B	A	A	B
Germantown to Pilgrim Rd.	4,660	4,660	4,430	4,430	10,200	8,000	8,000
Pilgrim Rd. to Butler	1,400	480	800	340	5,800	630	520
Donges Bay to Appleton Ave.	1,800	2,400	1,780	1,850	8,200	5,000	7,500
Butler to 70th St.	15,500	17,500	8,640	9,960	29,400	26,700	23,360
Total	23,360	25,040	15,650	16,580	53,600	40,300	39,380
Average	24,000		16,200		53,600	39,840	

A is use of groundwater data.
B is use of surface water data.

for > 80% of the increase in surface flow. The small amount of groundwater discharge to the river along this reach provides little dilution capability to the sewage treatment plant effluent.

Losing reaches of the Menomonee River

Heavy pumpage of groundwater from wells located near the stream has created conditions where surface water elevations are higher than groundwater elevations causing a reversal of the natural flow direction leading to surface water recharge of the groundwater system. The infiltration of surface water to the groundwater system was investigated a. to quantify the rate of infiltration to be used to compute a water budget for the Basin and b. to investigate the possibility that surface water contaminants were moving into the groundwater system. This portion of the report deals only with the rate of surface water infiltration and not contaminant movement.

The potentiometric map of the Niagara dolomite (1), was used first to identify possible losing reaches of the Menomonee River System by locating areas where heads in the dolomite were lower than stream channel levels. The stream was gauged along these reaches but produced inconclusive data. Measurements of water levels in observation wells indicated that the water table at sites 1, 6, 8 and 13 was lower than the surface water level. A portable piezometer, constructed of a 1.3 m (4 ft) length of stainless steel tubing, was used in the spring and fall of 1977 to define the losing reaches more accurately. These reaches are shown in the shaded areas of Figs. I-8 to I-10.

Groundwater levels at well sites 1 and 6 were found to be several meters lower than the river level, indicating that the groundwater may be separated from the surface water along these reaches. As mentioned previously, the river channel in these areas is underlain by lacustrine clay which, because of its low permeability, could effectively seal off surface flow from groundwater.

Groundwater temperature data shown in Fig. I-16, indicate that interaction between surface water and groundwater does occur. Groundwater temperatures at sites 1 and 6 fluctuated more than groundwater temperatures along discharge reaches of the stream (site 9). This greater fluctuation is thought to be caused by surface water movement into the groundwater. Infiltrating surface water will retain much of its original heat and warm the groundwater in summer causing higher than normal groundwater temperatures; the opposite occurs in winter.

The time lag between the occurrence of temperature maximums and minimums in the surface water and groundwater were used to estimate surface water recharge rates. The period of time in which a slug of warm or cold water takes to move from the surface down to a specified depth in the groundwater, divided by the vertical distance gives an estimate of the vertical velocity of the infiltrating water. The increased time lag in winter months is caused by increased viscosity of colder water producing slower movement.

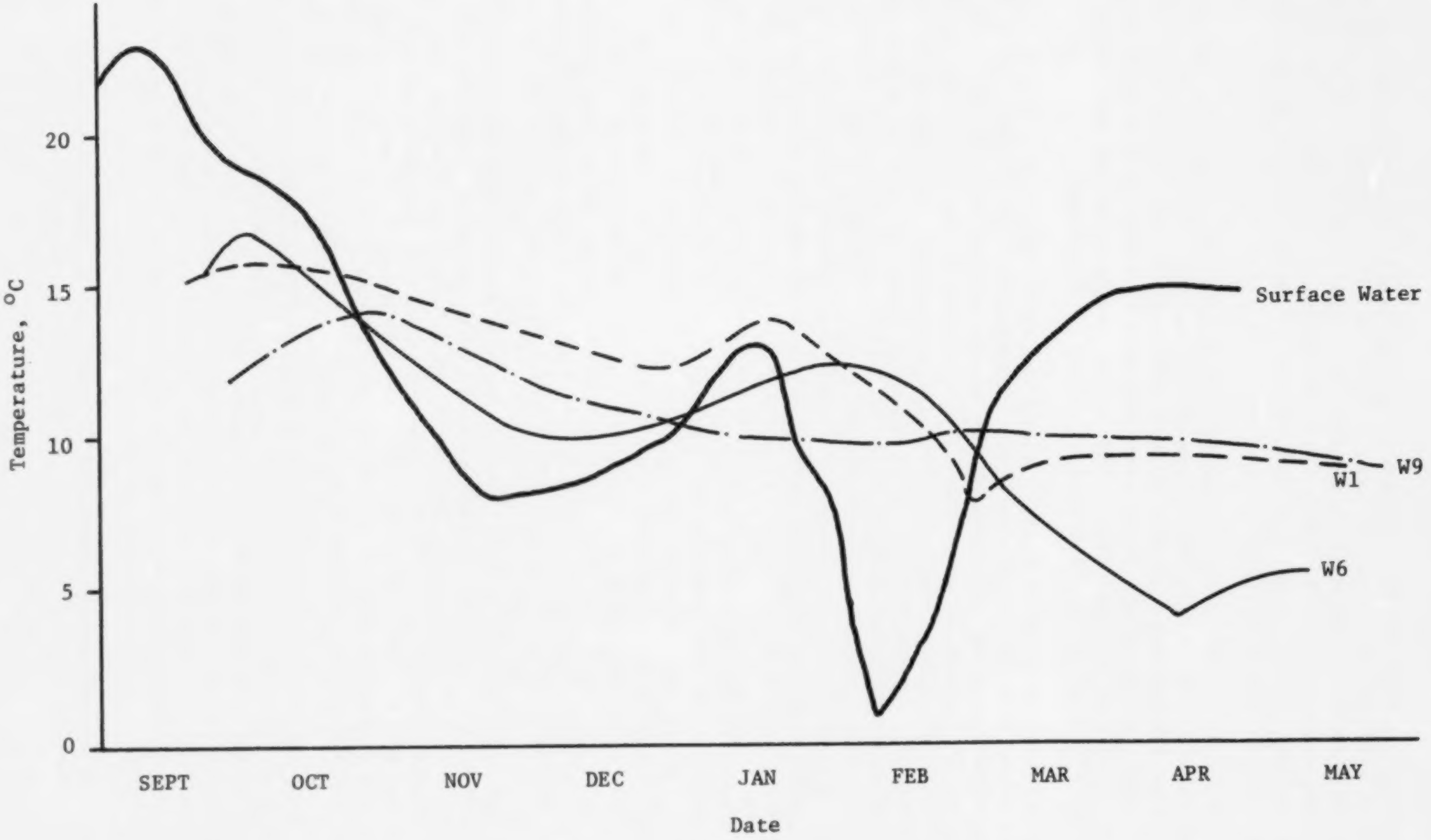

Fig. I-16. Plot of groundwater-surface water temperatures. W6 and W1 near losing reaches of the Menomonee River, W9 near gaining reach of the Little Menomonee River.

From the analysis of temperature it was estimated that the vertical velocity of infiltrating water at site 6 (Pilgrim Road) varies from 0.09 to 0.18 m/d (0.3 to 0.6 ft/d) with an average velocity of 0.14 m/d (0.46 ft/d). Infiltrating water at site 1 (124th St.) was estimated to have a vertical velocity ranging from 0.06 to 0.09 m/d (0.20 to 0.30 ft/d) with an average velocity of 0.07 m/d (0.23 ft/d).

The velocity of water multiplied by the area of pore space in the cross-sectional area of the stream bed allows determination of quantity of surface water lost to groundwater. Based on this calculation, the losing reach of the Menomonee River at Menomonee Falls was estimated to recharge the groundwater at a rate of 1970 m^3/d (0.52 mgd). The losing reach at Butler was estimated to recharge the groundwater at a rate of 870 m^3/d (0.23 mgd).

Infiltration rates vary greatly along the total reach of a losing stream. Rahn (19) found that in the Fenton River, Connecticut, the highest infiltration rate occurred along the sides of the stream channel because of the low permeability of the stream bed material in contrast to the horizontal permeability of the material along the sides of the channel. In areas where large head differences between surface water and groundwater elevations occur, e.g., sites 1 and 6, movement of surface water is essentially vertical. These estimates of infiltration rates are viewed as being minimum amounts of surface flow lost to groundwater. Infiltration rates are probably higher farther away from the pumping wells, where the separation between surface water and groundwater is not so great and surface water may flow horizontally through the sides of the channel to the groundwater system. Where a hydraulic separation of the groundwater-surface water does occur, the infiltration rate of surface water is governed by the permeability of the least permeable material in the streambed. Moore and Jenkins (20) suggest a maximum rate of 0.8 m/d (20 gpd/ft^2) as a reasonable first approximation. This value overestimates minimum infiltration rate for these reaches of the Menomonee River since the streambed is underlain with very fine lacustrine clay. Using the infiltration rates calculated above it is estimated that the vertical permeability of this clay is less than 0.08 m/d (2 gpd/ft^2).

Seepage collectors also were used to measure infiltration rates along the losing reach of the river in Menomonee Falls. The seepage collectors were constructed from 190-liter drums that were cut about 30 cm from the top. A hole was drilled into the lid of the drum and a plastic bag was attached. The collector was placed into the streambed. The measurement of water moving in or out of the seepage collector gives a direct estimate of groundwater discharge or surface water infiltration.

The data obtained from the seepage collectors were less than ideal. Duplicate tests gave different results, with the first measurement generally being much larger than the second. Streambed disturbance occurring during installation of the collectors may have caused the initial results to be artifically high. Seepage collectors probably need to be placed into the streambed and allowed to sit for a number of days before accurate measurements can be obtained.

Using the second set of measurements, the infiltration rates were estimated to be 720 m^3/d (0.19 mgd). This is approximately a factor of about two times less than the estimates obtained from temperature data. While it was expected that seepage rates away from the high capacity well would be larger, seepage collectors measured smaller rates. The results are viewed as estimates.

The average non-event flow of the Menomonee River at Butler is about 15,000 m^3/d (4 mgd). The combined volume of surface water lost to groundwater is approximately 2840 m^3/d (0.75 mgd) or about 19% of total flow. Since > 80% of the increase in river flow between Menomonee Falls and Butler is attributed to treated waste discharge, it is likely that much of the surface water lost to groundwater is recycled wastewater. Curtailment of these discharges might reduce greatly the flow of the Upper Menomonee River.

Groundwater Quality and Loading Rates

The nature and concentrations of dissolved constituents in natural groundwater are dependent on the composition of the aquifer through which the groundwater flows. Back (16), Garrels and Mackenzie (21) and Maclay and Winter (22) found significant correlations between groundwater quality and aquifer composition. Water in calcareous sediments tends to be dominated by calcium, magnesium and bicarbonate ions. Water in marine-clay sediments tends to have higher proportions of sodium and chloride with lower concentrations of calcium and bicarbonate. Sulfate which is normally associated with evaporites is commonly found in low concentrations in waters from all types of marine sediments.

The main factors that affect dissolution are temperature, pressure, the area of the interface between soluble minerals, the volume of water and the time of contact. It is generally accepted that as the length of the groundwater flow path increases the groundwater tends to have higher concentrations of dissolved solids. Mineralization also increases with decreased permeability of the aquifer because of the larger surface area in contact with the groundwater and the slower movement of groundwater through the medium.

Changes in the chemical composition of groundwater can occur as a result of various types of land use practices. For example, increased chloride concentrations in groundwater can be caused by evapotranspiration of irrigation waters (7), roadsalt runoff (23) and seepage of landfill leachates (24). Nutrients (nitrogen and phosphorus) might be supplied to the groundwater through fertilizer application, feedlot runoff and septic tank effluent (25). Table I-3 shows comparisonsof natural sources for various constituents in groundwater to those introduced by man.

Regional water quality

Groundwater in the Wisconsin-Lake Michigan Basin is generally of good quality. The major ions in solution are calcium and bicarbonate. Concentrations of total dissolved solids in the glacial and Niagara aquifers average 200 to 400 mg/L and some increase in mineralization occurs in the southern

Table I-3. Natural versus artificial sources of various chemical constituents found in groundwater wells

Parameters	Sources in Natural Groundwater	Artificial Sources
Calcium	Dissolution of carbonates, evaporites and weathering of igneous rocks (anorthite).	Road salt, evaporation of irrigation water.
Magnesium	Dissolution of carbonates, weathering of ferro-magnesium minerals in igneous rocks.	
Sodium	Dissolution of evaporites, weathering of igneous rocks (albite), cation exchange in clays.	Road salt, evaporation of irrigation water.
Potassium	Weathering of igneous rocks (orthoclase), cation exchange in clays.	Potash-fertilizer application.
Chlorides	Dissolution of evaporites, anion exchange in clays.	Road salt, evaporation of irrigation water, septic tank effluent, seepage of landfill leachates.
Carbonate/ bicarbonate	Dissolution of carbonates, precipitation, oxidation of organic material.	
Sulfates	Dissolution of evaporites, oxidation of organic material, oxidation of sulfides (pyrite).	Oxidation of industrially produced sulfides, seepage from landfills.
Nitrogen	Oxidation of organic material.	Fertilizer application, barnyard runoff, septic tank effluent.
Phosphorus	Oxidation of organic material.	Fertilizer application, barnyard runoff, septic tank effluent.
Lead, cadmium, zinc, copper, chromium, nickel	Concentrations in natural waters usually low--sources are sulfide deposits and mineral veins.	Industrial discharges, automobile exhaust, seepage from landfill leachates.

portion of the Basin (17).

The regional groundwater system has nitrate concentrations averaging > 0.5 mg/L of nitrogen. Concentrations as high as 20.5 mg/L of nitrogen have been measured in some wells. Phosphate is generally not found in the Niagara and glacial aquifers (17).

Water quality of glacial aquifer in the Menomonee River Basin

The groundwater of the shallow aquifer system in the Menomonee River Basin is generally of good quality but often contains high concentrations of total dissolved solids, chloride and sulfate. Nitrate concentrations are usually low but ammonia concentrations as high as 1.5 mg/L of nitrogen were found in some areas.

Major anions and cations

Fig. I-17 shows the averages and ranges in concentration of the major anions and cations found in the glacial and Niagara aquifers in the Menomonee River Basin compared to regional concentrations found in the aquifers throughout the Wisconsin-Lake Michigan Basin; regional averages were taken from (17).

Groundwater from the glacial aquifer sampled during this study contained concentrations of total dissolved solids which averaged over 100% higher than the regional averages and the average for the Niagara aquifer. Average chloride concentrations in the Basin were found to be as much as 900% higher. Sulfate concentrations vary from 60 to 200% higher and associated cations also are found in higher concentrations.

Data for the glacial aquifer in the Menomonee River Basin, presented by (1) differ from data obtained during this investigation. The difference is related to the number of analyses obtained and the well locations. The SEWRPC reported groundwater analyses of samples from 5 private wells taken during one sampling period. The wells selected were located in rural areas which have relatively thick deposits of permeable material that yield an adequate supply of relatively good quality water for domestic use.

The averages reported from the present study are for several groundwater samples obtained during a 12 month period and include seasonal changes in water quality. Many of the groundwater samples were obtained from urban areas and tend to characterize the glacial aquifer in terms of urban effects on water quality rather than the more natural conditions found in rural areas. Moreover, many of the well sites were located in areas covered by till deposits where groundwater would have somewhat higher concentrations of dissolved solids compared to groundwater in sand and gravel deposits (22).

Multiple linear regression analysis was used as a statistical tool to identify the physical and chemical parameters which best identify the occurrence of a certain water quality. The list of parameters used in the analysis and the

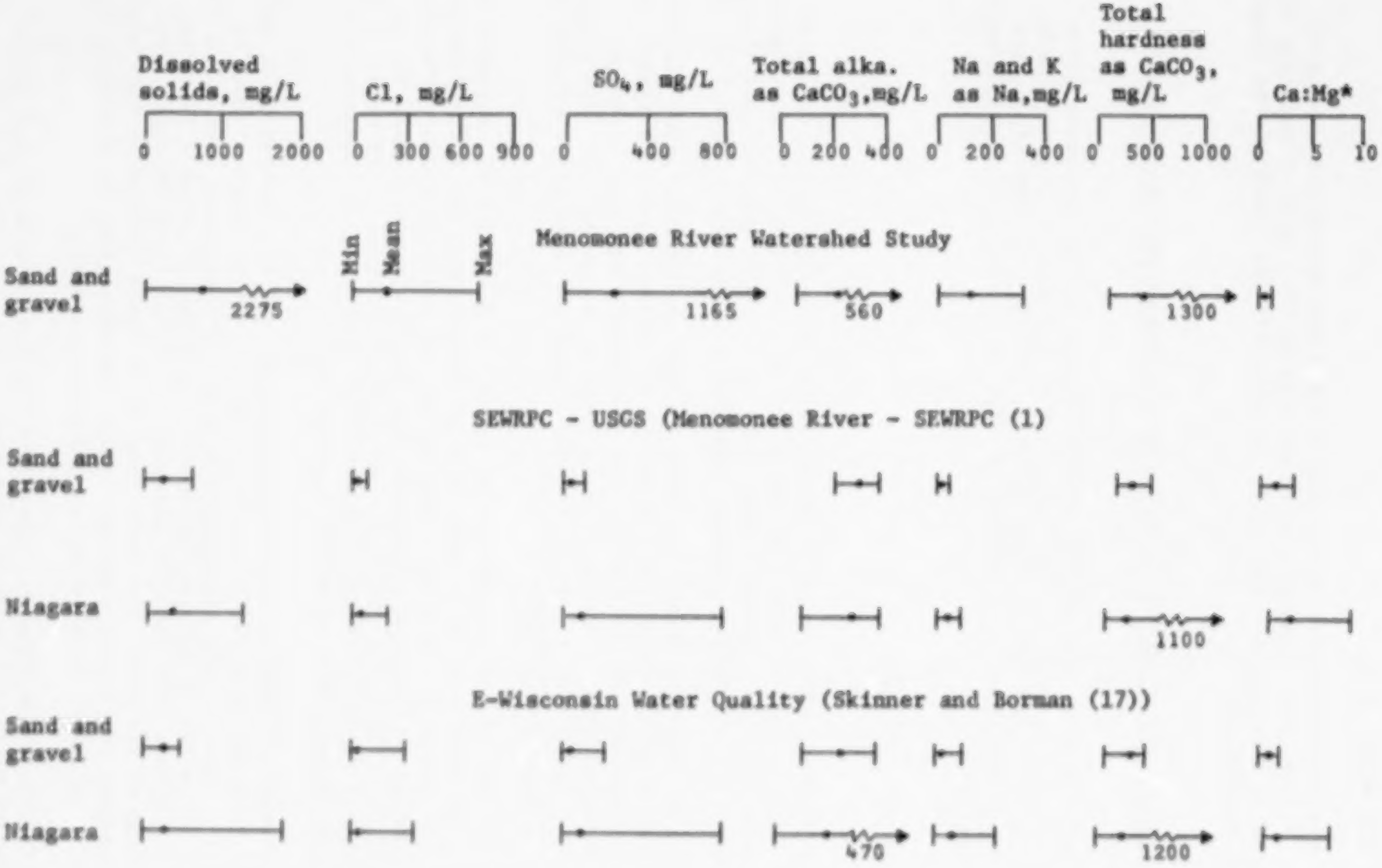

Fig. I-17. Comparison of water quality of the glacial aquifer of the Menomonee River Basin to the regional quality for the Wisconsin-Lake Michigan Basin.
*Based on equivalent values.

correlation coefficients are shown in Table I-4. The regression analysis was run at a 95% confidence level with F limits set at 4.0. Detailed analytical data on ground and surface water quality are given in Appendix B.

Variations in the chemical composition of groundwater were not dependent upon physio-geologic parameters such as depth within the aquifer, location within the flow system, aquifer composition, or temperature. Changes in hydrochemical composition may however be related to specific land use practices not included in the regression analysis.

The analysis indicated that the concentration of total dissolved solids (TDS) is best predicted by measuring concentrations of sulfate and chloride in groundwater samples. The regression equation TDS [mg/L] = (260.3 ± 17) + 1.662 ± 0.17 [SO_4 mg/L] + 1.982 ± 0.19 [Cl mg/L] gave an r^2 value of 0.966 and a standard deviation of 90.4. The plot of observed TDS versus predicted TDS is shown in Fig. I-18. The addition of specific conductance--which had the best individual correlation with TDS (0.903)--to the regression equation added only 1.2% to the explained variation (r^2). The addition of alkalinity (as $CaCO_3$) added only 0.7% to the explained variation.

Bicarbonate and calcium are the dominant ions in solution for most of the Wisconsin-Lake Michigan Basin (17). Therefore, variation in calcium carbonate content in general should correlate with changes in TDS. However, the hydrochemical variation in the Menomonee River Basin is better described by the analysis of chloride and sulfate concentrations. The average calcium carbonate concentration (alkalinity as $CaCO_3$) was measured at 260 ± 37 mg/L (5.4 ± 0.7 meq/L). The average concentration found for chloride was 180 ± 130 mg/L (5.1 ± 3.7 meq/L), while the average sulfate concentration is 188 ± 95 mg/L (4.0 ± 2 meq/L). The sum of chloride and sulfate milliequivalents in solution are almost twice the milliequivalents of bicarbonate. The ranges of chloride and sulfate in solution also are much higher than the ranges of bicarbonate. Thus, the regression equation of TDS versus chloride and sulfate can best describe the variation of mineralization in the groundwater. Chloride and sulfate are the dominant ions in solution but vary greatly in amount throughout the Basin. Bicarbonate ions are found in about the same concentrations as in groundwater in the Wisconsin-Lake Michigan Basin (Fig. I-16), but are no longer the most abundant ions in solution.

These changes in the hydrochemistry of the glacial aquifer system are also shown by the use of trilinear plots of the anion/cation ratios in solution. Trilinear plots have been used successfully by (22) to develop relationships between water quality, aquifer composition, and groundwater flow patterns. A similar analysis was attempted but water quality variations were too random to be separated categorically on the basis of flow patterns or aquifer material. Instead, the trilinear plots show a change in water quality from rural to urban areas. The upper diagram in Fig. I-19 shows Ca-Mg-HCO_3 groundwater in the far left portion, with increasing percentages of sulfate towards the top of the diagram and increasing percentages of Na-Cl towards the right. Notice that the regional average compositions of groundwater from the Niagara dolomite and the glacial aquifers have high percentages of Ca, Mg and HCO_3 ions in solution. The groundwater from the Niagara dolomite in the Menomonee River Basin has only slightly more sulfate and chloride and its composition is shifted a little upwards and to the right.

Table I-4. Correlation coefficients for water quality data

	Conductivity	Total dissolved solids	Sulfate	Chloride	Alkalinity	Phosphate	Nitrate	Ammonia	Temperature	Well depth	Recharge-discharge	pH	Aquifer medium
Conductivity	1.000												
Total dissolved solids	0.903	1.000											
Sulfate	0.683	0.742	1.000										
Chloride	0.602	0.666	0.028	1.000									
Alkalinity	0.563	0.556	0.528	0.093	1.000								
Phosphate	-0.002	-0.024	-0.119	0.102	-0.057	1.000							
Nitrate	-0.035	-0.012	-0.056	0.003	0.018	-0.051	1.000						
Ammonia	0.234	0.249	0.092	0.320	0.039	0.348	-0.116	1.000					
Temperature	0.094	0.032	-0.001	0.003	0.061	0.062	-0.045	-0.154	1.000				
Well depth	-0.159	-0.113	-0.050	-0.155	-0.068	-0.139	0.190	-0.264	0.198	1.000			
Recharge-discharge	0.188	0.225	0.218	0.237	-0.139	0.062	-0.126	0.031	-0.073	-0.192	1.000		
pH	-0.379	-0.427	-0.236	-0.330	-0.433	-0.132	-0.091	-0.097	-0.088	0.209	-0.196	1.000	
Aquifer medium	0.113	0.226	0.413	-0.140	-0.221	0.065	-0.217	0.065	-0.036	-0.089	-0.213	*	1.000

*pH vs aquifer medium correlation not computed.

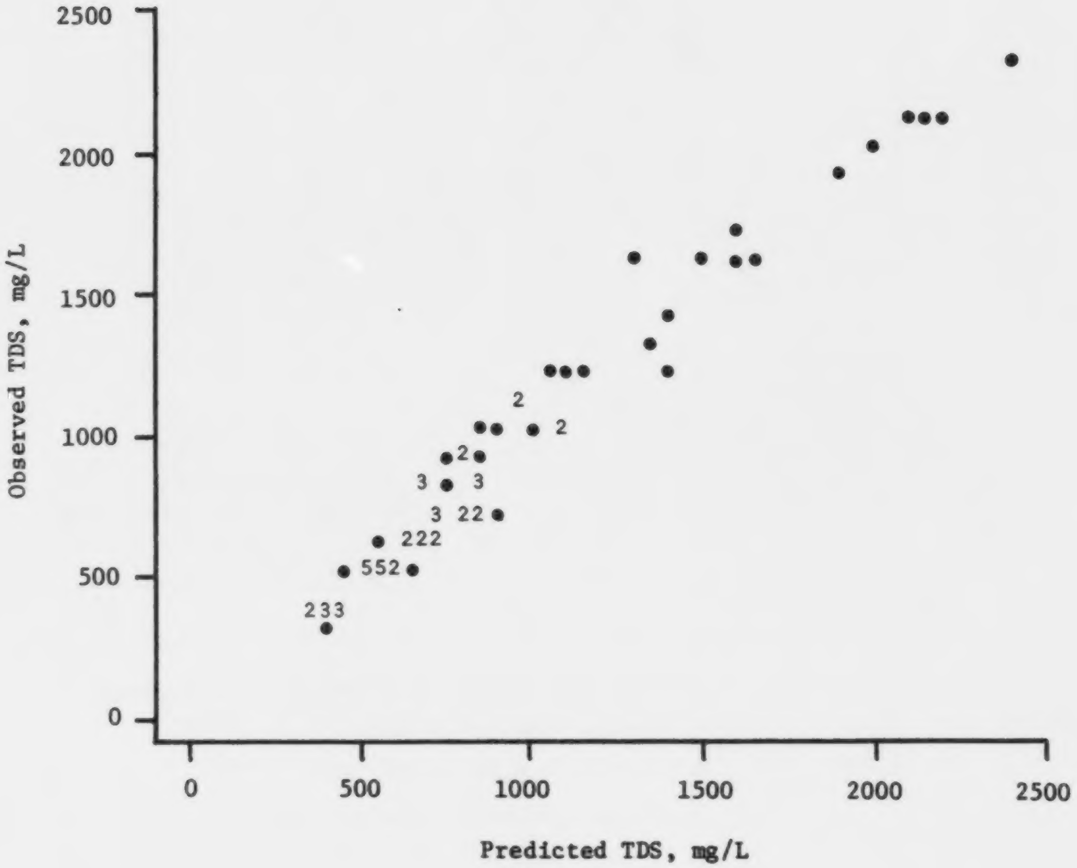

Fig. I-18. Observed versus predicted values for total dissolved solids (TDS); numbers represent multiple data points.

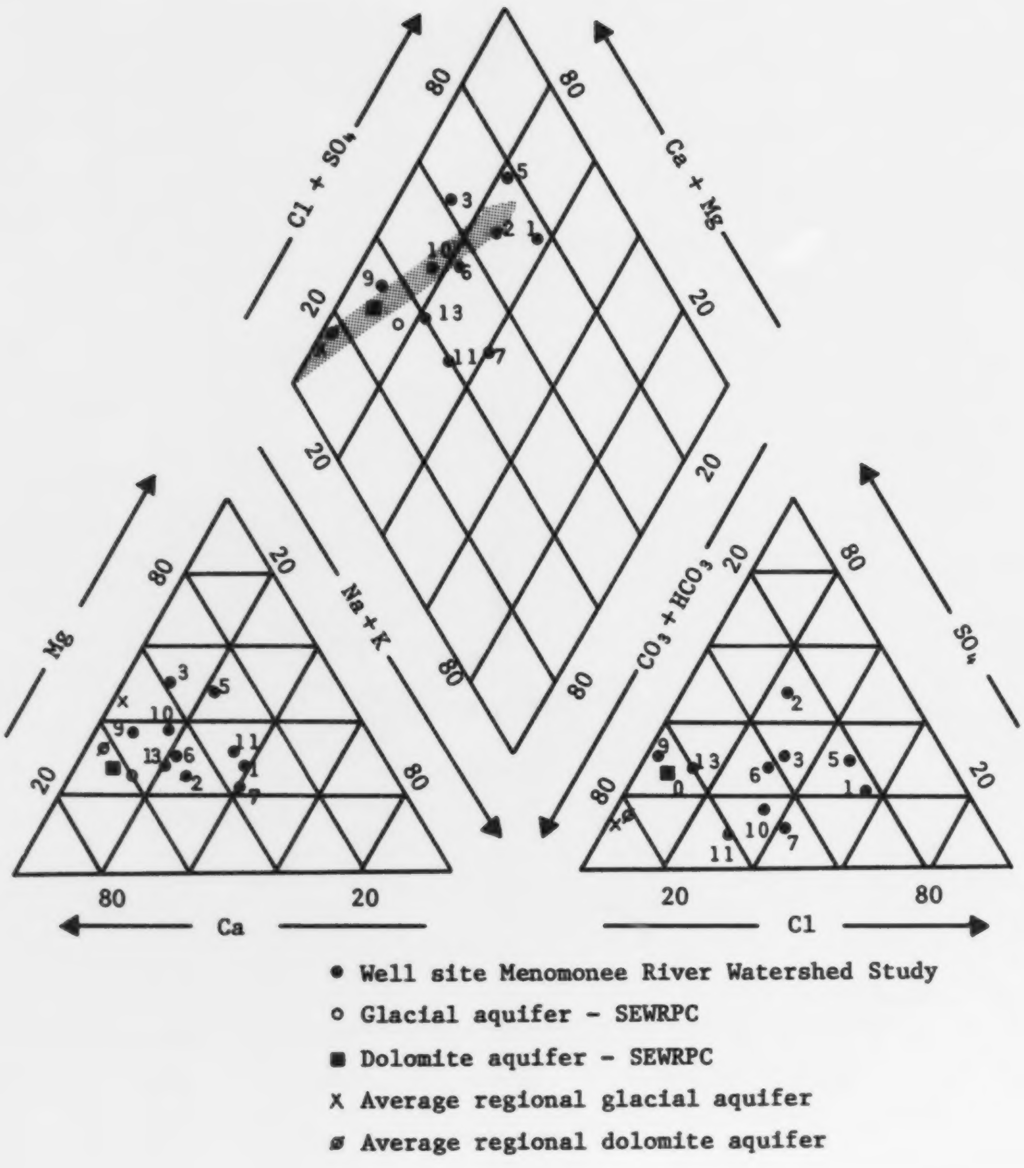

Fig. I-19. Trilinear plot of anion/cation ratios (% of total meq/L) for local and regional groundwater quality. Shaded arrow points toward deviation from regional water quality.

The groundwater from well sites 9 and 13--located in low density residential areas and the average composition of the glacial aquifer as reported by SEWRPC--have compositions comparable to the quality of regional water. The groundwater from sites 7 and 11 show about a 15% increase in chloride concentration relative to other ions in solution with no increase in sulfates.

The greatest deviation from regional hydrochemistry is found at sites 1, 2, 3 and 5 all of which are located in the high density residential or industrial portion of the watershed. In these groundwaters, < 40% of the anions in solution are bicarbonate. Both sulfate and chloride percentages increase about 40 to 60% over regional averages, relative to other ions in solution. While calcium and magnesium ions still comprise the majority of cations in solution, the sodium plus potassium concentration increased from 10 to 20% over that found for regional water quality.

The increasesin chloride and sulfate in the shallow groundwater suggest a deterioration of the groundwater quality in certain areas of the Menomonee River Watershed. Mineralization is undesirable in waters used for most industrial purposes and high sodium concentrations in drinking water can be a health hazard to people with cardio-vascular problems (7).

Similar data were found in the Chicago area (23). A comparison of water from the dolomite aquifer in northeastern Illinois from the 1930's to 1973 indicated that the concentrations of all ions in solution increased. The largest increases were 840% for Cl, 140% for SO_4 and 90% for Na.

The source of increased chloride found in the groundwater is probably from deicing salt. For years, road salts have been used in increasingly larger amounts. Fig. I-20 shows the areal distribution and seasonal variation of chloride concentrations found in the Menomonee River Basin. Notice the high concentrations of chloride in the middle and southern portions of the Basin where wells were located near highways (sites 2, 3, 5, 7). Highest concentrations occurred during winter and spring which coincides with times when largest amounts of road salt are used.

Spatial and seasonal variations of sulfate concentrations are shown in Fig. I-21. The highest concentrations of sulfate were measured in spring. Most of the sulfate salts are less soluble than corresponding chloride salts and may cause an accumulation of sulfate salts on the ground surface during the year, with dissolution and movement into the groundwater occurring only in the spring when maximum runoff occurs.

The increase in sulfate may be due to SO_4 ions in rainfall resulting from the oxidation of industrially-produced sulfide. Hem (25) reports that up to 10 mg/L SO_4 may be found in rain water around urban areas. Evapotranspiration may concentrate the sulfate, resulting in a surface residue which can be redissolved only during ground saturated conditions in the spring. Another possible source of sulfate is from landfills. Many low lying areas of the Menomonee River floodplain have been filled during the construction of parks. Old building materials such as wall board have probably been used in these old landfills and may have a localized effect on the shallow groundwater quality. In some wells, high sulfate contents may be caused by upwelling of mineralized water from bedrock aquifers. Ranges of total dissolved solids are shown in Fig. I-22.

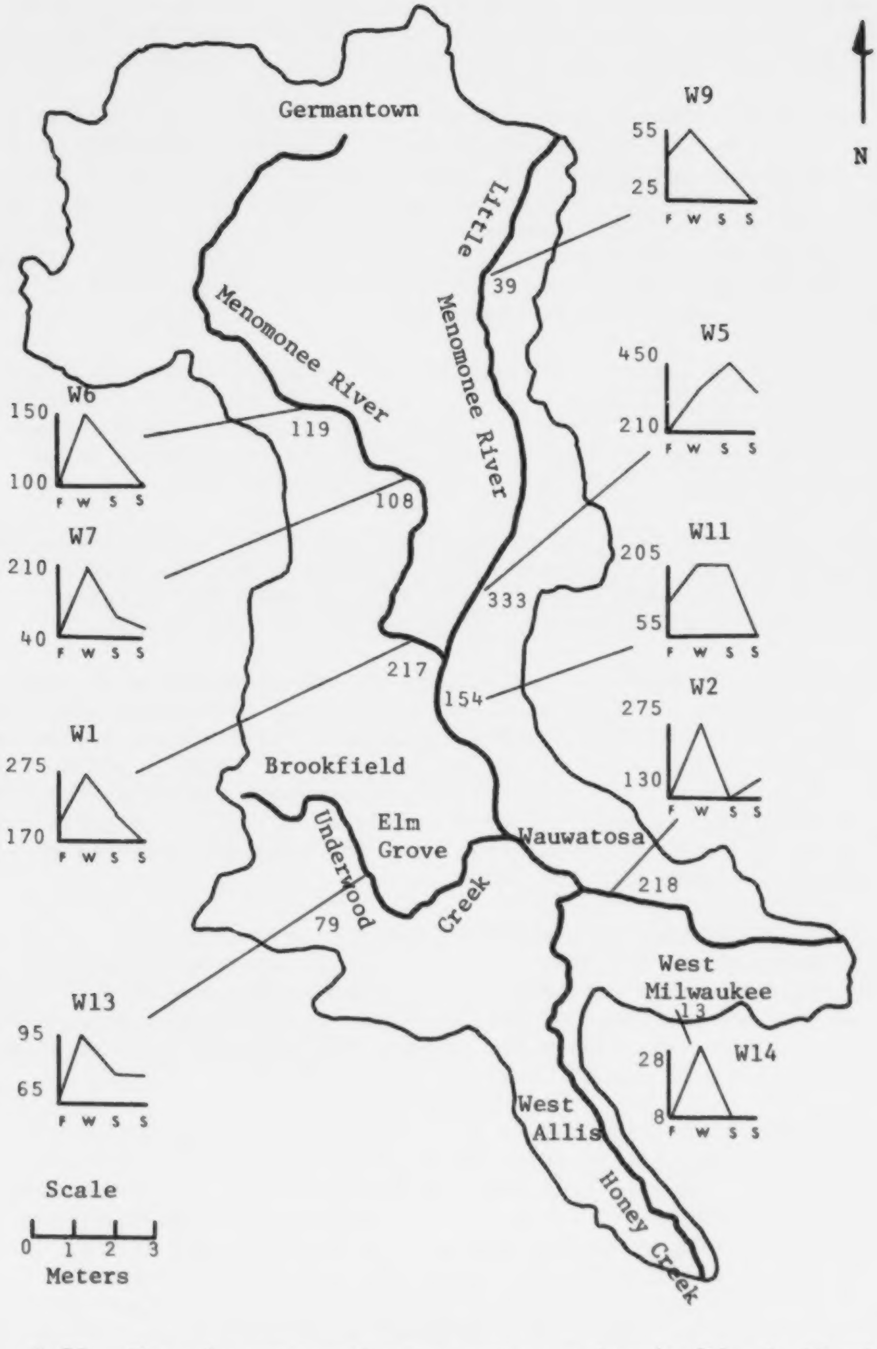
Germantown
N
W9
55
25
F W S S
39
Little Menomonee River
Menomonee River
W5
450
210
F W S S
W6
150
100
F W S S
119
108
W7
210
40
F W S S
333
W11
205
55
F W S S
217
154
W2
275
130
F W S S
W1
275
170
F W S S
Brookfield
Elm Grove
Underwood Creek
Wauwatosa
218
79
West Milwaukee
13
W14
28
8
F W S S
W13
95
65
F W S S
West Allis
Honey Creek
Scale
0 1 2 3
Meters

Fig. I-20. Map of ranges and mean concentrations (mg/L) of chloride for Fall, Winter, Spring and Summer at selected sites in the Menomonee River Basin.

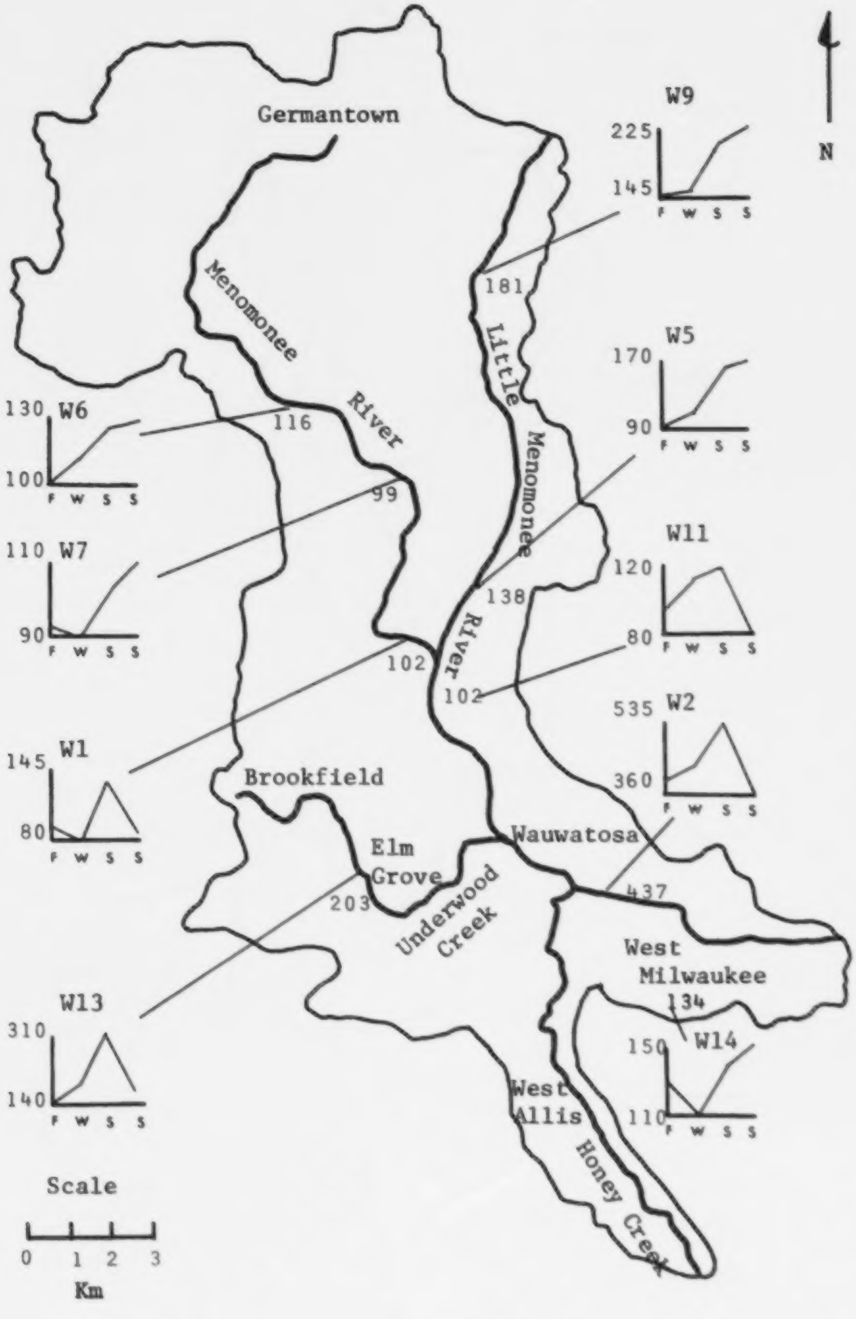
N
Germantown
W9
225
145
F W S S
181
Menomonee
River
Little
Menomonee
River
W5
170
90
F W S S
130 W6
100
F W S S
116
99
110 W7
90
F W S S
138
W11
120
80
F W S S
102
102
W1
145
80
F W S S
535 W2
360
F W S S
Brookfield
Elm
Grove
203
Wauwatosa
437
Underwood
Creek
West
Milwaukee
134
W13
310
140
F W S S
150 W14
110 F W S S
West
Allis
Honey
Creek
Scale
0 1 2 3
Km

Fig. I-21. Map of ranges and mean concentrations(mg/L) of sulfate for Fall, Winter, Spring and Summer at selected sites in the Menomonee River Basin.

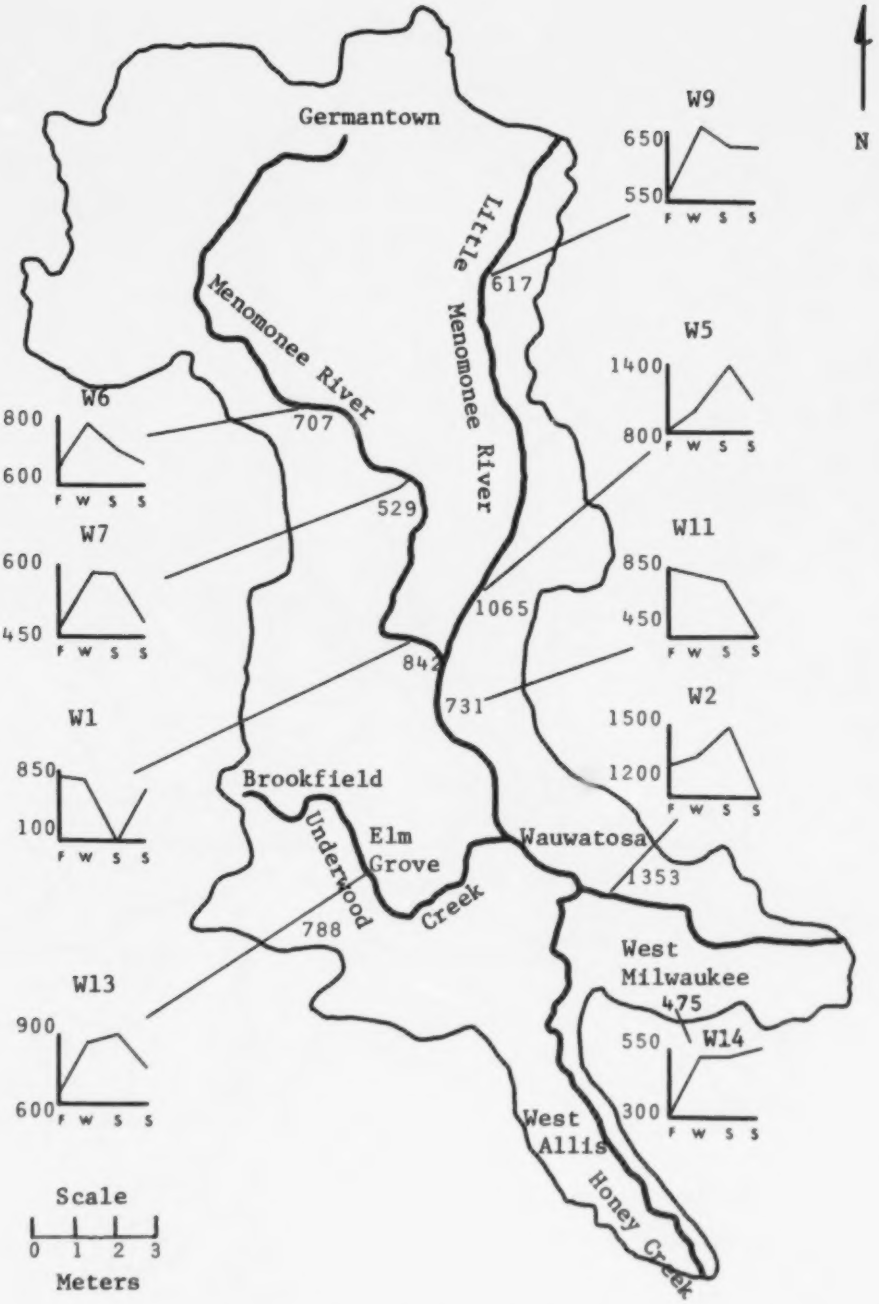
Germantown
W9
650
550
F W S S
617
N
Little Menomonee River
Menomonee River
W5
1400
800
F W S S
W6
800
600
F W S S
707
529
W7
600
450
F W S S
1065
W11
850
450
F W S S
842
731
W1
850
100
F W S S
W2
1500
1200
F W S S
Brookfield
Underwood Creek
Elm Grove
Wauwatosa
1353
788
West Milwaukee
475
W13
900
600
F W S S
550
W14
300
F W S S
West Allis
Honey Creek
Scale
0 1 2 3
Meters

Fig. I-22. **Map of ranges and mean concentrations (mg/L) of total dissolved solids for Fall, Winter, Spring and Summer at selected sites in the Menomonee River Basin.**

Nutrients

Nutrient concentrations in groundwater have become of increasing interest in recent years (26). Groundwater seepage into inland lakes and streams may contribute a substantial amount of nutrients, especially during dry periods. Sources of nutrients in groundwater include the infiltration of nitrogen and phosphorous compounds from fertilizers and barnyard manure and seepage from septic tanks.

Nitrogen concentrations in groundwater in the Menomonee River Basin occasionally exceeded the critical concentrations of nitrogen needed for algal growth which is 0.3 mg/L of nitrogen, according to Sawyer (27). Nitrate concentrations of 1.0 mg/L of nitrogen or more were found in a survey of the groundwater in the northern agricultural portion of the Watershed. The lower two-thirds of the Watershed had low concentrations of nitrate. Only a few groundwater samples from this portion of the watershed contained nitrate above the analytical detection limit of 0.02 mg/L of nitrogen.

The groundwater in the lower portion of the watershed was found to have relatively high concentrations of ammonia, especially in low lying areas adjacent to the Menomonee River. Well sites 1, 5 and 7 showed the highest concentrations of ammonia, with some groundwater samples exceeding 1.0 mg/L of nitrogen. Nitrogen compounds in the groundwater usually exist in the oxidized nitrate form (25) and the identification of the sources of the ammonia in the groundwater at these sites is very difficult. The presence of ammonia in the groundwater may be caused by the low permeability of the aquifer and the bog-like reducing conditions in these low lying areas.

At well site 1 in Butler, the Menomonee River is known to be influent, that is, losing water. High ammonia concentrations have been found in the Menomonee River (1); therefore, the river may supply ammonia to the groundwater. This site is also near sewage lines that cross the river. Use of rhodamine dye as a tracer indicated that leakage from these lines was occurring. Therefore, leaky sewage lines may be another possible source of ammonia.

Well site 7 is adjacent to an effluent (gaining) reach of the Menomonee River, but it is also near sewage lines that were found to leak. This area also has many faulty septic systems which could supply nitrogen compounds to the groundwater (Vogt, personal communcation, 1977).

Phosphate levels in the groundwater were found to be very low. Few analyses were above the critical concentration considered to be necessary for algal blooms which is 0.015 mg/L of phosphorus according to Sawyer (27). Since most of the soil material in the basin consists of clay- and silt-sized particles and contains large amounts of $CaCO_3$, it is expected that phosphate compounds would be tightly bound in the soil column and would not be mobile in the groundwater system.

Bacteriology of the groundwater

The presence of fecal coliforms in a water sample is used widely as an indicator of pathogenic bacteria in that water. Fecal coliform bacteria are harmless organisms which exist in the intestinal tracts of all warm-blooded animals. The presence of fecal coliform bacteria in water samples suggests the possible existence of disease producing organisms. The presence of coliform bacteria may or may not be an indicator of fecal contamination inasmuch as coliform bacteria inhabit soil.

Although the presence of fecal coliform bacteria can be measured accurately, studies indicate that analyses for fecal streptococci ("fecal strep") may be a better indicator of sewage contamination (28, 29). "Fecal streps" do not multiply in surface waters and rarely occur in soil. "Fecal streps" have been reported to survive longer than *Escherichia coli* and can be regarded as delayed indicators when fecal coliform are not found or measured in low concentrations.

Standards established by the Wisconsin Department of Natural Resources limit the total coliform concentrations for treated drinking water to 1 colony/100 ml of water. Water for recreational purposes should not exceed 400 colonies/100 ml for more than 10% of the samples during any month. Standards have not been set for "fecal strep" concentrations (1).

Bacterial analyses of groundwater in the Menomonee River Basin were initiated by the observation that some test wells produced waters which contained offensive odors similar to sewer gas. Generally these wells were located close to sewage lines and it was speculated that leakage of sewage from these pipes might be occurring.

Groundwater samples for bacterial analyses were obtained by bailing. The bailer was submerged in alcohol and ignited between samples to prevent contamination of other samples.

Bacterial analyses were performed initially by the Village of Menomonee Falls Hydraulics Laboratory for groundwater samples from 12 test wells located in and around the Menomonee Falls-Butler area. Water samples were tested using the Multiple Tube Fermentation Technique (30). Both presumptive and confirmed tests resulted in positive identification of coliform bacteria for all wells.

Since coliform bacteria can live in soil systems, an additional analysis was needed to determine whether the bacteria were of fecal origin. Using the Membrane Filter Technique (30), total coliform, fecal coliform, and fecal streptococci analyses were performed on a second set of groundwater samples from these wells. The tests performed at the Water Chemistry Unit of the Environmental Sciences Section of the Wisconsin State Laboratory of Hygiene, indicate substantial fecal bacterial contamination of the groundwater. None of the samples was suitable for drinking water and only about 50% have bacterial concentrations considered suitable for recreational use (Table I-5).

The results of these analyses are surprising because several groundwater

Table I-5. Bacterial composition of water from selected test wells in the Butler-Menomonee Falls Area

Well No.	Total number of coliform colonies/100 ml	Number of fecal coliform colonies/100 ml	Number of fecal streptococci colonies/100 ml
1-1* (10 m**)	150	80	26
1-2* (10 m**)	Plate overgrown with noncoliform bacteria	16	26
1-4*	40	4	30
6-1* (30 m**)	460	44	220
6-2* (30 m**)	730	300	200
6-4* (30 m**)	360	240	130
7-1* (10 m)	570	96	780
7-2* (10 m)	450	170	520
7-3* (15 m)	240	104	800
7-5* (20 m)	Plate overgrown with noncoliform bacteria	2	110
8-2*	40	30	20
9-1	16	10	6

*Located in losing reach of Menomonee River.
**Approximate distance from sewage line.

studies have indicated that movement of bacteria is usually attenuated within the first few feet of travel through unsaturated soil (25, 28). Although studies in Europe have shown lower bacterial attentuation capabilities in saturated soils (31) none of the investigations surveyed reported movement through silt-clay materials over a distance as great as those found in this study.

The possibility exists that some infiltration occurred along the sides of the well casing. However, all wells were clay packed, and mounded above the ground surface and were protected against surface contamination. It is not known how bacteria are transported through clayey till. Desiccation cracks formed during low groundwater periods may be present, providing a conduit for transport. Land disturbance during road or building construction in the area also may have caused cracks large enough for bacterial transport. Dye tracer studies have confirmed that leakage from sewage lines was occurring to some of the test wells. Because high bacteria concentrations also are found along losing reaches of the river, some bacteria may result from surface water infiltration.

Metals

High concentrations of lead, zinc, copper and occasionally cadmium have been measured in surface waters in the Menomonee River Watershed (6). The sources of the metals in surface waters are thought to be from automobile exhausts and industrial discharges. Possible sources of the metals in groundwater are atmospheric fallout, landfill leachate and infiltration of stream waters.

Analyses for the metals in the groundwater samples for two sampling periods indicated that no metal tranport occurred in the shallow groundwater system. Most analyses showed concentrations of the metals at or below detection limits (I-B-2).

The low concentrations of metals in the groundwater is not surprising. Field and column studies conducted by the Illinois State Geological Survey (32) showed that the metals are adsorbed readily by clays, and precipitate as oxides, sulfates or hydroxides at pH 7 or above. Because the Menomonee River Basin is covered mainly by clayey tills, and the groundwater is semi-alkaline with high sulfate contents, metal cations are not mobile in the groundwater.

Groundwater loading rates to Menomonee River

Estimates of the seasonal groundwater loading rates for three reaches of the Menomonee River System are shown in Table I-6. The loadings were estimated from the amount of groundwater discharge along these reaches and from the concentrations of ions in solution measured from wells adjacent to the river. Variations in the seasonal loadings result from changes in rates of groundwater discharge and variations in ion concentrations.

Table I-6. Groundwater loadings

Reach	Discharge rate, m^3/day	TDS, kg/day	Sulfate, kg/day	Chloride, kg/day	CaCo$_3$, kg/day	Dissolved phosphate-P, kg/day	Total nitrogen, kg/day
Fall 1976							
Germantown to Butler (Menomonee River)	5,000	4,440	659	1,250	1,963	0.2	1.8
Dongee Bay Rd. to Appleton Ave. (Little Menomonee River)	2,100	2,610	420	452	956	0	0.9
Butler to 70th St. (Menomonee River)	16,500	28,800	5,040	5,544	6,840	1.2	7.1
Total	23,600	35,870	6,119	7,246	9,764	1.4	9.8
Winter 1976-77							
Germantown to Butler (Menomonee River)	5,000	4,070	500	1,131	1,573	0.1	4.5
Dongee Bay Rd. to Appleton Ave. (Little Menomonee River)	1,800	1,400	263	287	399	0.2	0.7
Butler to 70th St. (Menomonee River)	9,400	12,100	2,092	3,429	3,088	0.2	3.7
Total	16,200	17,570	2,835	4,847	5,060	0.5	8.9
Spring 1977							
Germantown to Butler (Menomonee River)	16,000	10,900	1,700	2,500	4,400	0.1	11.8
Dongee Bay Rd. to Appleton Ave. (Little Menomonee River)	8,200	8,100	500	2,000	2,000	0	3.1
Butler to 70th St. (Menomonee River)	29,400	38,100	8,000	8,500	9,800	0	10.0
Total	53,600	57,100	10,200	12,000	16,400	0.1	24.9

For purposes of the IJC-Menomonee River Pilot Watershed Study, only two parameters are of major interest, namely, chloride and total nitrogen. While phosphate concentrations are high in the surface water, they were seldom found in groundwater. Sulfate was measured in high concentrations in groundwater, but few sulfate analyses have been conducted on surface waters.

Comparisons of the groundwater loadings to base flow loadings for chlorides and total nitrogen are shown in Table I-7. Because of time constraints and lack of base flow water quality data no comparisons can be shown for the summer of 1977. Estimates of surface flow loadings were supplied by the Wisconsin Department of Natural Resources in cooperation with the IJC-Menomonee River Pilot Watershed Study.

From the fall of 1976 to the spring of 1977, groundwater supplied 51 to 82% of the chloride found in surface waters. During the winter of 1976-77 chloride was found in the highest concentrations in groundwater, but resulted in the smallest seasonal percentage of surface water loadings (51%) due possibly to the high concentrations of salts moving directly into the river from street drainage. Notice that in the fall of 1976, the groundwater supplied only 50% of the base flow (Fig. I-12) while the groundwater loadings of chloride was 82% of base flow.

The groundwater loadings of inorganic nitrogen comprised a smaller percentage of base flow loadings than found for chlorides. The groundwater accounted for 12 to 24% of the base flow nitrogen levels, with the greatest loading occurring in the spring. This increased discharge of nitrogen compounds in the spring was caused by increased groundwater discharge into the river, rather than higher concentrations of nitrogen compounds.

The high concentrations of inorganic nitrogen in the river water are caused by discharges from sewage treatment plants. Notice the large river loadings which occur from Germantown to Butler. The loss of nitrogen in the surface waters from Butler to 70th St. may result from biological uptake, adsorption by stream bed sediments, or diffusion of ammonia into the atmosphere. No major increase of nitrogen compounds were found in the groundwater along losing reaches of the river, indicating that the high concentrations of dissolved ammonia in the surface waters are being adsorbed or atmospherically lost before entering the groundwater system.

Summary of groundwater quality

Groundwater samples collected did not have significant concentrations of metals, phosphate or nitrogen compounds. Groundwater in localized areas had high concentrations of fecal bacteria, but it is doubtful that this shallow groundwater would be used for domestic water supplies. It is not known how deep in the groundwater system bacterial contamination occurs.

Although no encroachment of toxicants into the shallow groundwater system has occurred, it has become increasingly saline from the input of chlorides and sulfates. These ions have changed significantly the general hydrochemistry of the aquifer and may show a long term detrimental effect on the water resources of the basin.

Table I-7. Comparison of groundwater (GW) loadings to base flow (SW) loadings in the Menomonee River

Reach	Chlorides, kg/day		Ratio of chlorides GW:SW	Inorganic nitrogen*, kg/day		Ratio of nitrogen GW:SW
	GW	SW		GW	SW	
			Fall 1976			
Germantown to Butler (Menomonee River)	1,249	3,713	0.34	1.8	87.0	0.02
Donges Bay Rd. to Appleton Ave. (Little Menomonee River)	452	363	1.24	0.9	0.3	3.00
Butler to 70th St. (Menomonee River)	5,544	4,939	1.12	7.1	-8.2	
TOTAL	7,245	8,815	0.82			
			Winter 1976-77			
Germantown to Butler (Menomonee River)	1,131	4,500	0.25			
Donges Bay Rd. to Appleton Ave. (Little Menomonee River)	287	903	0.31			
Butler to 70th St. (Menomonee River)	3,429	3,884	0.88			
TOTAL	4,847	9,461	0.51			
			Spring 1977			
Germantown to Butler (Menomonee River)	2,500	9,457	0.26			
Donges Bay Rd. to Appleton Ave. (Little Menomonee River)	2,000	2,633	0.76			
Butler to 70th St. (Menomonee River)	8,500	6,958	1.22			
TOTAL	12,000	19,048	0.63			

*Ammonia and nitrite-nitrate nitrogen.

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APPENDIX I-A. WELL SITES

Table I-A-1. Street locations of well sites

Site number	Location
W1	Menomonee River at 124th St., Butler
W2	Menomonee River at 70th St., Wauwatosa
W3	Honey Creek, west of West Honey Creek Pkwy., Milwaukee
W4	Menomonee River in Currie Park, Milwaukee
W5	Little Menomonee River at Appleton Ave., Milwaukee
W6	Menomonee River at Pilgrim Rd., Menomonee Falls
W7	Menomonee River near Fond du Lac Ave. at Milwaukee-Waukesha County line
W8	Menomonee River at Lilly Rd., Menomonee Falls
W9	Little Menomonee River at Donges Bay Rd., Mequon
W10	South of Good Hope Rd. in Noyes Park, Milwaukee
W11	South of Concordia Pkwy. in Concordia Park, Milwaukee
W12	Underwood Creek above Hwy. 45 off North Ave., Milwaukee
W13	Underwood Creek at Municipal Grounds, Elm Grove
W14	West Milwaukee Park, West Milwaukee

Table I-A-2. Location of wells, well construction and depth*

Well No.	Location	Depth, m	Construction
Site: W1 124th St. in Butler Land Use: Industrial, residential			
W1-1	3 m north of Menomonee River (M.R.) adjacent to USGS monitoring station	7.8	Polyvinyl chloride (PVC)
W1-2	Next to W1-1	5.2	PVC
W1-3	22.5 m north of M.R., 9 m west of 124th St.	5.9	Galvanized Steel
W1-4	9 m south of M.R., south of W1-1 and W1-2	8.9	PVC
Site: W3 Adjacent to Honey Creek, west of Honey Creek Parkway Land Use: Medium density residential, near interstate highway			
W3-1	180 m west o' 84th St., 12 m north of Honey Creek Parkway	6.0	PVC
W3-2	Next to W3-1	9.3	Galvanized Steel
Site: W5 Little Menomonee River at Appleton Ave. Land Use: Medium density residential, commercial			
W5-1	1.5 m west of USGS monitoring station on Dike 3m south of river	5.7	PVC
W5-2	30 m southwest of River	5.7	PVC
W5-3	9 m north of River, 30 m southwest of Appleton Ave.	4.0	PVC
W5-4	Next to W5-3	6.6	Galvanized Steel
Site: W7 Menomonee River near Fond du Lac Ave. at Milwaukee-Waukesha County Line Land Use: Agriculture, low density residential			
W7-1	9 m south of M.R., 12 m east of county line	9.1	Galvanized Steel
W7-2	Next to W7-1	5.0	PVC
W7-3	10.5 m north of M.R., 12 m east of county line	9.1	Galvanized Steel
W7-4	Next to W7-3	2.6	PVC
W7-5	105 m north of M.R., 30 m east of county line	3.5	PVC
Site: W9 Little Menomonee River (L.M.R.) at Donges Bay Rd. Land Use: Agriculture			
W9-1	4.5 m west of L.M.R., 9 m north Donges Bay Rd.	2.9	PVC
Site: W11 Concordia Park Land Use: Medium to high density residential			
W11-1	9 m south of Townsend Rd., 30 m east of park entrance rd.	12.6	Galvanized Steel
W11-2	Next to W11-1	6.1	PVC
Site: W13 Underwood Creek at Municipal Grounds Land Use: Low density residential			
W13-1	3 m east of Underwood Cr., 75 m north of municipal grounds entrance road	8.4	Galvanized Steel
W13-2	Next to W13-1	2.9	PVC
W13-3	21 m west of Underwood Cr., 69 m west of entrance road	8.9	Galvanized Steel
W13-4	Next to W13-3	2.9	PVC

Well No.	Location	Depth, m	Construction
Site: W2 Menomonee River at 124th St. Land Use: High density single family residential, industrial			
W2-1	57 m south of M.R., 9 m west of 70th St.	7.8	PVC
W2-2	9 m south of M.R., 9 m north of Honey Creek Parkway	4.4	PVC
W2-3	4.5 m north of M.R., 39 m west of 70th St.	6.5	Galvanized Steel
W2-4**	Next to W2-3	3.3	PVC
Site: W4 Menomonee River in Currie Park Land Use: Medium density residential, commercial			
W4-1	45 m northwest of M.R., 150 m south of Capitol Dr.	4.8	PVC
Site: W6 Menomonee River at Pilgrim Rd. Land Use: Medium density residential			
W6-1	12 m south of M.R., next to USGS station	15.9	Galvanized Steel
W6-2	Next to W6-1	9.6	PVC
W6-3	6 m north of M.R., 45 m west of Pilgrim Rd.	7.0	PVC
W6-4	Next to W6-3	10.2	Galvanized Steel
Site: W8 Menomonee River at Lily Rd. Land Use: Medium density residential			
W8-1**	15 m east of Lily Rd., 9 m north of M.R.	4.1	PVC
W8-2	22.5 m east of Lily Rd., 3 m south of M.R.	3.5	PVC
Site: W10 Good Hope Rd., in Noyes Park Land Use: Park and medium density residential			
W10-1	30 m south Good Hope Rd., 15 m west of park entrance road	12.9	Galvanized Steel
Site: W12 Underwood Creek above Hwy. 45 off North Ave. Land Use: Park and commercial			
W12-1[+]	10.5 m south of Underwood Cr., adjacent to USGS monitoring station	8.4	Galvanized Steel
W12-2[+]	Next to W12-1	2.8	PVC
Site: W14 West of Milwaukee Park Land Use: Medium density residential			
W14-1	6 m south of Mitchell St., 9 m east of park entrance road	8.9	PVC
W14-2**	Next to W14-1	5.0	PVC

*See Fig. I-4, page I-11.

**Data collection interrupted after 1 month because of vandalism.

+Data collection interrupted after 2 months because of vandalism.

Table I-A-3. Well logs

Well No.	Depth, m	Description
W1-1	0 to 0.9	Light brown sandy soil, some gravel
	0.9 to 5.2	Dark brown-gray clayey till, bouldery with gravel
	5.2 to 7.0	Brown-gray clay, some small pebbles, cohesive
	7.0 to 8.7	Gray silt with fine sand, runny
	8.7	Bedrock
W3-2	0 to 3.6	Brown sandy fill, some silt and gravel
	3.6 to 6.0	Gray sandy silt, some clay and rounded dolomitic pebbles, sand fine grained semi-round
	6.0 to 11.4	Gray silty sand of fine to coarse grain, semi-round
	11.4 to 12.3	Gray clay till, some angular dolomitic gravel
W5-2	0 to 0.9	Sand and gravel fill
	0.9 to 4.5	Poorly sorted, semi-angular sand and gravel
	4.5 to 5.4	Well sorted, rounded pea-sized gravel
	5.4 to 7.2	Gray clay till with gravel and boulders
	7.2	Bedrock
W7-1	0 to 1.5	Light brown sand and gravel, poorly-sorted with some silt
	1.5 to 3.0	Gray clay till with angular gravel
	3.0 to 7.2	Gray sandy silt, sand is fine to medium grained and subangular
	7.2 to 11.4	Gray clay till with sand, gravel and boulders, subangular, some plant debris
	11.4 to 12.9	Gray clay till, little sand, cohesive
W9-1	0 to 0.9	Dark brown organic soil
	0.9 to 2.4	Brown sandy till, some clay and silt
	2.4 to 5.4	Bouldery gray clay till, some angular gravel
	5.4	Bedrock
W11-1	0 to 1.8	Light brown sand and gravel, some silt, poorly sorted
	1.8 to 3.9	Light brown clay, some fine sand
	3.9 to 6.0	Light brown clay till, some sand and gravel, subangular
	6.0 to 9.0	Light brown fine to coarse silty sand, dolomitic, subrounded, poorly sorted
	9.0 to 9.9	Gravelly silty sand
	9.9 to 12.9	Gray clay and layers of fine sand
W13-1	0 to 0.9	Black, silty organic soil
	0.9 to 3.9	Gray sandy silt, very fine grained, well rounded
	3.9 to 6.6	Medium sand, well sorted, some silt, subrounded, dolomitic
	6.6 to 9.9	Gray coarse sand, some silt, subangular

Well No.	Depth, m	Description
W2-1	0 to 3.0	Light brown silty sand, sand well rounded, dolomitic, fine to medium grained
	3.0 to 4.5	Gray silty sand, sand is fine grained, dolomitic
	4.5 to 5.4	Gray sandy silt, some clay, cohesive
	5.4 to 12.9	Gray silty sand, fine grained, well-sorted
	12.9	Bedrock
W4-1	0 to 2.4	Brown sandy fill with gravel, some silt, fine to coarse grained sand
	2.4 to 4.8	Gray clay till, bouldery
	4.8	Bedrock
W6-1	0 to 1.8	Sand and gravel poorly sorted, some silt
	1.8 to 2.7	Dark brown silt, some clay, little sand
	2.7 to 4.8	Dark gray clay, cohesive, no sand or gravel
	4.8 to 6.6	Light brown silty sand, fine to medium grained, well rounded, dolomitic
	6.6 to 9.6	Tan, medium grained sand, some silt, poorly-sorted
	9.6 to 15.0	Light brown fine grained silty sand, cohesive
	15.0 to 16.5	Gray clay till with sand and angular gravel
W8-1	0 to 1.8	Brown silty clay, little sand, compacted
	1.8 to 3.9	Light brown silty sand, fine grained, well sorted, subrounded
	3.9 to 6.9	Light brown gravel with some sand and silt, poorly sorted, subangular
W10-1	0 to 1.5	Brown sandy soil, some gravel
	1.5 to 3.9	Brown clay
	3.9 to 7.5	Gray clay, pea-sized pebbles, little sand
	7.5 to 12.9	Gray clay, cohesive
W12-1	0 to 1.5	Brown sand and gravel fill
	1.5 to 2.7	Black silty muck
	2.7 to 3.9	Gray silty sand, fine grained, dolomitic, subrounded
	3.9 to 9.0	Light brown fine to coarse sand, some silt, poorly sorted, subrounded
	9.0 to 10.5	Gray muddy gravel, poorly sorted, angular
W14-1	0 to 3.9	Light brown fine to coarse sand, subrounded, dolomitic
	3.9 to 9.9	Silty sand, fine to medium grained, subrounded, dolomitic, cohesive when wet

APPENDIX I-B. WATER QUALITY DATA

Table I-B-1. Groundwater quality data

Well	Date	Depth*, m	pH	Specific cond. at 25°C	Total dissolved solids, mg/L	SO_4, mg/L	Cl, mg/L	Alkalinity, mg/L	PO_4-P, μg/L	NO_3-N, μg/L	NH_3-N, μg/L	Temp, °C
Well Site No. W1												
W1-1	9/76	7.9A	7.9	1875	690	105	120	315	6	0	900	13.2
3	9/76	6.1A	7.6	1875	1190	60	390	280	170	0	280	12.9
4	9/76	9.1B	7.9	680	425	95	42	180	5	240	30	12.5
1	10/76	7.9A		1395	940	70	200	430	18	0	560	13.0
2	10/76	5.5A		1335	780	75	310	275	210	0	210	13.9
3	10/76	6.1A		1430	910	175	150	385	0	20	220	12.1
1	12/76	7.9A		1585		71	620		210	30	450	12.0
2	12/76	5.5A		1535		81	420		24	0	510	13.0
4	12/76	9.1B		455		72	72		12	20	190	10.0
1	2/77	7.9A	8.1	1450	1095	87	275	270	4	0	240	12.1
2	2/77	5.5A	7.9	1790	995	110	230	390	0	0	460	12.1
4	2/77	9.1B	7.9	560	395	82	34	175	0	0	280	10.1
2	3/77	5.3A	7.7	1740	1150	145	275	390	0	0	430	10.9
3	3/77	5.9A	8.0	1350	845	140	110	425	0	0	170	10.5
2	4/77	5.3A	8.1	1525	975	68	315	260	0	0	510	10.4
3	4/77	5.9A	8.4	1610	1060	215	180	400	0	0	180	9.5
1	5/77		7.6	1260	955	133	230	270	0	140	880	11.2
2	5/77		7.5	1100	890	130	195	270	0	110	830	14.2
4	5/77		8.0	1050	880	78	65	320	0	0	130	10.1
1	6/77		8.5	1250	915	54	300	235	0	0	660	12.9
2	6/77		7.8	1350	925	93	250	310	0	0	450	11.1
3	6/77		8.0	1010	790	150	105	285	0	0	270	11.1
4	6/77		7.8	510	350	67	31	180	0	20	570	11.0
1	7/77		8.0	1130	860	78	300	225	9	30	680	12.5
2	7/77		7.6	1100	800	92	195	395	8	20	610	12.8
4	7/77		7.8	500	325	60	26	185	7	0	510	11.0
Well Site No. W2												
W2-1	9/76	7.9B	7.8	1650	1645	395	300	335	5	0	240	11.2
3	9/76	6.7B	8.0	1835	765	175	140	205	9	0	230	14.8
1	10/76	7.9B		2130	1960	950	60	310	19	0	240	11.0
2	10/76	4.6B		2120	1620	400	350	380	16	0	210	12.2
3	10/76	6.7B		1000	585	130	130	235	5	0	240	12.0
1	12/76	7.9B		1485		575	160		8	40	500	10.9
2	12/76	4.6B		1520		440	680		14	30	330	10.0
3	12/76	6.7B		540		130	260		3	0	90	9.9
1	2/77	7.9B	7.8	2725	1920	920	60	550	4	0	360	11.0
2	2/77	4.6B	7.6	2750	1590	370	370	460	0	0	200	10.1
3	2/77	6.1B	8.2	1305	700	225	130	200	4	0	80	7.8
1	3/77	7.9B	7.6	2570	2135	1030	65	560	0	0	240	11.0
2	3/77	4.4B	7.5	2420	1715	375	370	460	0	0	180	9.5
3	3/77	6.6B	8.4	1230	745	165	140	230	0	0	90	9.6
1	4/77	7.9B	7.7	2485	2115	1060	65	445	0	0	170	10.0
2	4/77	4.4B	7.6	1680	1630	400	370	345	0	0	170	9.1
3	4/77	6.6B	8.5	1160	780	180	135	250	0	0	150	7.8
1	5/77		8.1	2670	1960	540	215	360	0	0	60	13.0
2	5/77		7.5	2400	1800	520	340	320	0	0	230	11.0
1	6/77		7.6	1650	1330	680	40	240	0	7	450	11.0
2	6/77		7.6	1950	1560	395	365	325	0	0	230	10.0
3	6/77		8.5	1100	815	165	135	245	0	0	120	12.0
2	7/77		7.6	1980	1450	405	365	420	8	0	240	11.5
3	7/77		8.1	1040	830	150	135	235	6	0	190	14.0

*A is recharge and B is discharge.

Table I-B-1. Cont.

Well	Date	Depth*, m	pH	Specific cond. at 25°C	Total dissolved solids, mg/L	SO_4, mg/L	Cl, mg/L	Alkalinity, mg/L	PO_4-P, µg/L	NO_3-N, µg/L	NH_3-N, µg/L	Temp, °C
					Well Site No. W3							
W3-2	10/76	9.5A		1165	805	180	100	340	19	0	300	8.0
2	12/76	9.5A		510		195	240		3	30	340	9.9
1	2/77	6.4A	8.1	2070	1610	215	349	430	0	0	330	11.0
2	2/77	9.2A	8.1	1285	1180	280	180	390	0	0	290	10.0
2	5/77		7.7	1950	1640	320	550	325	0	0	110	12.0
2	6/77		8.2	2000	1655	230	480	310	0	30	180	12.9
					Well Site No. W5							
W5-1	10/76	5.8B		420	190	40	3	105	11	0	290	10.8
2	10/76	4.3B		2120	1445	115	475	250	5	0	110	14.1
3	10/76	4.0B		870	765	120	150	230	4	20	380	14.1
1	12/76	5.8B		300		75	14		4	400	60	10.1
2	12/76	4.3B		1335		115	700		8	0	80	10.5
3	12/76	4.3B		965		140	380		3	0	880	10.0
1	2/77	5.8B	8.2	495	385	75	34	180	114	60	290	9.0
3	2/77	4.3B	8.0	1720	1200	170	430	75	4	0	410	7.5
4	2/77	6.7B	7.9	980	1390	180	430	295	0	0	1300	8.0
1	3/77	6.7B	8.1	500	310	75	4	160	8	150	80	5.4
2	3/77	4.1B	7.8	1650	1010	110	300	340	0	0	70	7.9
4	3/77	6.7B	7.7	2435	2275	150	950	225	0	0	1200	7.6
2	4/77	5.8B	7.8	1625	1270	170	400	240	0	0	40	8.0
3	4/77	4.1B	8.1	2640	1950	325	610	230	0	0	1200	11.0
1	5/77		7.8	1200	950	130	230	220	0	130	450	9.8
2	5/77		7.8	1640	1335	220	430	320	0	90	820	10.1
1	6/77		8.2	430	325	80	7	160	0	160	190	9.0
2	6/77		7.8	1950	1480	195	490	245	0	20	90	11.5
4	6/77		7.8	2000	1465	260	440	220	0	0	800	9.1
1	7/77		8.0	500	295	75	10	160	16	160	120	11.0
2	7/77		8.0	1670	1725	220	675	305	7	0	80	14.0
3	7/77		8.0	1850	1335	200	415	315	6	0	590	13.5

Table I-B-1. Cont.

Well	Date	Depth*, m	pH	Specific cond. at 25°C	Total dissolved solids, mg/L	SO_4, mg/L	Cl, mg/L	Alkalinity, mg/L	PO_4-P, µg/L	NO_3-N, µg/L	NH_3-N, µg/L	Temp, °C
					Well Site No. W6							
W6-3	9/76	7.3A	7.3	820	915	88	180	370	16	30	340	11.0
4	9/76	10.4A	8.1	800	550	95	68	275	5	0	140	13.0
1	10/76	16.2A		1300	590	130	65	275	0	20	100	9.1
2	10/76	9.8A		1300	595	80	90	300	13	20	70	10.1
2	12/76	9.8A		610		93	220		3	3	60	11.0
3	12/76	7.3A		500		85	140		6	0	150	11.0
4	12/76	10.4A		525		105	135		0	0	310	11.0
1	2/77	16.2A	8.1	980	625	125	70	270	0	0	230	10.2
2	2/77	9.8A	7.8	1120	930	135	170	310	0	2300	90	9.8
2	3/77	9.8A	8.0	1350	940	145	185	315	0	2200	60	8.0
4	3/77	10.4A	8.6	750	490	105	70	180	0	30	200	1.8
2	5/77		8.2	830	645	120	105	290	0	880	200	10.2
4	5/77		8.0	860	740	88	92	295	0	260	110	8.0
1	6/77		8.4	720	565	95	55	275	0	60	360	9.8
2	6/77		8.6	690	735	130	100	270	0	470	150	14.4
3	6/77		8.4	1000	705	135	93	250	0	40	840	10.9
4	6/77		8.3	750	580	105	125	190	0	60	360	10.9
2	7/77		8.0	1050	825	185	98	270	6	100	60	15.0
4	7/77		8.2	790	630	145	130	170	4	30	780	8.5
					Well Site No. W7							
W7-1	9/76	9.1A	8.2	775	530	85	38	330	8	0	220	13.0
2	9/76	5.2A	8.2	605	355	100	14	165	0	40	240	11.9
3	9/76	7.3B	8.2	800	520	105	60	240	16	40	180	16.9
1	12/76	9.5A		475		80	68		8	0	0	9.5
2	12/76	5.2A		450		130	700		38	80	590	9.8
3	12/76	7.3B		530		110	240		17	20	340	8.9
4	12/76	2.7B		1050		69	110		23	0	330	9.0
5	12/76	3.7B		475		71	130		8	0	90	9.0
1	2/77	9.5A	8.3	660	420	74	50	210	0	0	60	6.2
2	2/77	5.2A	8.0	1250	745	105	175	335	6	0	2700	6.3
1	3/77	9.3B	8.5	750	495	93	100	190	0	0	160	8.5
2	3/77	5.0B	7.8	780	535	73	54	340	0	0	270	8.0
4	3/77	2.6B	7.8	1405	990	145	270	315	180	0	2600	6.8
5	3/77	3.6B	7.7	970	625	83	135	300	0	410	40	7.0
1	4/77	9.3B	8.5	915	530	96	120	185	0	0	280	11.0
2	4/77	5.0B	8.0	805	490	90	46	280	0	0	270	12.0
3	4/77	7.2B	7.5	625	385	90	46	120	0	0	280	7.0
4	4/77	2.6B	8.2	1060	625	130	115	270	19	0	980	8.0
1	5/77		8.0	825	630	41	95	265	0	20	910	13.0
2	5/77		7.6	710	505	60	53	245	0	0	420	13.0
3	5/77		7.9	660	465	75	50	230	0	0	850	10.9
1	6/77		8.3	710	500	90	98	190	0	0	540	12.9
2	6/77		7.9	625	445	85	37	260	0	0	300	14.9
3	6/77		7.9	630	475	115	120	48	0	20	430	11.0
4	6/77		8.4	805	655	130	80	280	54	30	880	11.0
5	6/77		7.9	600	435	62	40	220	0	700	100	10.5
2	7/77		8.0	650	405	105	60	330	7	20	350	17.5
4	7/77		7.6	650	440	170	105	56	4	0	310	13.0

Table I-B-1. Cont.

Well	Date	Depth*, m	pH	Specific cond. at 25°C	Total dissolved solids, mg/L	SO_4, mg/L	Cl, mg/L	Alkalinity, mg/L	PO_4-P, µg/L	NO_3- N, µg/L	NH_3- N, µg/L	Temp, °C
Well Site No. W8												
W8-2	2/77	3.1A	8.2	750	500	76	32	300	5	0	300	4.0
2	3/77	3.5A	8.1	690	430	60	19	315	0	0	200	6.2
2	5/77		7.9	830	655	37	165	288	0	0	690	10.1
2	6/77		8.7	450	320	29	8	245	0	0	100	21.0
Well Site No. W9												
W9-1	10/76	3.1B		1045	565	145	40	225	4	0	160	9.8
1	12/76	3.1B		560		135	80		41	0	260	5.0
1	2/77	3.1B	8.1	870	645	160	32	290	7	0	260	2.7
1	3/77	2.9B	8.0	890	615	190	38	270	0	0	210	5.1
1	4/77	2.9B	8.2	875	645	230	32	220	0	0	220	13.0
1	6/77		8.0	800	630	220	24	215	0	0	240	21.0
Well Site No. W10												
W10-1	10/76	13.1A		965	630	105	7	490	0	0	250	9.8
1	2/77	13.1A	8.8	740	545	145	14	115	4	0	610	9.5
1	6/77		8.6	620	475	62	0	345	0	40	410	11.2
Well Site No. W11												
W11-2	10/76	6.4A		845	845	95	150	400	16	240	70	10.8
1	12/76	13.4A		515		125	110		0	20	460	10.8
2	12/76	6.4A		1120		100	300		10	20	20	6.0
2	3/77	6.2A	8.2	1770	805	120	205	415	7	0	190	12.0
1	6/77		8.5	650	445	78	54	215	0	20	330	10.9
Well Site No. W12												
W12-1	9/76	8.5A	8.0	1165	1035	215	110	430	13	0	430	12.3
2	9.76	3.1A	7.9	890	350	70	5	175	8	30	210	14.3

Table I-B-1. Cont.

Well	Date	Depth*, m	pH	Specific cond. at 25°C	Total dissolved solids, mg/L	SO_4, mg/L	Cl, mg/L	Alkalinity, mg/L	PO_4-P, µg/L	NO_3-N, µg/L	NH_3-N, µg/L	Temp, °C
					Well Site No. W13							
W13-1	9/76	8.5A	7.8	875	725	150	70	340	8	0	30	13.5
2	9/76	3.1A	8.1	760	760	185	90	300	12	0	280	14.8
3	9/76	8.5A	8.5	805	520	110	44	260	8	20	0	13.0
4	9/76	3.1A	8.0	630	510	120	60	140	8	0	560	15.1
1	2/77	8.5A	7.8	1090	790	165	80	340	0	0	100	10.0
2	2/77	3.1A	8.2	1160	895	200	105	300	4	0	200	6.0
1	3/77	8.5A	7.8	960	680	125	80	340	0	0	70	4.0
2	3/77	2.9A	8.0	1105	730	180	100	285	0	0	230	5.0
3	3/77	8.3A	8.4	735	510	120	39	260	0	0	90	6.2
4	3/77	2.9A	7.6	1110	755	180	70	390	0	100	820	5.2
2	4/77	2.9A	8.5	1035	705	165	100	270	0	0	280	6.1
4	4/77	2.9A	8.1	2800	2115	1080	83	340	0	70	1040	6.0
1	5/77	2.9A	8.1	1080	800	150	100	255	0	0	330	8.5
4	5/77		8.2	980	780	200	40	245	0	0	410	10.0
1	6/77		8.4	900	675	115	75	330	0	0	130	13.0
3	6/77		8.5	680	540	105	48	250	0	0	80	14.0
4	6/77		7.7	1350	1070	370	82	315	0	0	1400	15.5
1	7/77		8.1	1040	800	165	105	265	0	0	210	10.0
2	7/77		8.0	980	740	130	80	330	0	0	0	14.5
					Well Site No. W14							
W14-1	10/76	9.2A		400	320	63	14	184	22	0	50	11.5
1	12/76	9.2A		300		85	48		16	0	0	10.1
1	2/77	9.2A	8.2	800	510	110	8	270	8	0	100	10.6
1	3/77	9.0A	8.1	845	515	145	8	275	0	20	100	10.0
1	6/77		8.5	730	555	155	9	280	0	20	90	11.0
					Well Site No. W1-A							
W1-A**	7/77		7.9	900	740	290	19	205	35	180	150	10.7
					Well Site No. W1-B							
W1-B**	7/77		7.7	790	590	100	39	360	0	1300	290	10.7
					Well Site No. W2-A							
W2-A**	7/77		8.0	700	495	96	34	275	18	1100	200	11.2
					Well Site No. W2-B							
W2-B**	7/77		8.6	640	415	54	54	255	13	1820	40	11.0
					Well Site No. W2-C							
W2-C**	7/77		8.2	750	515	95	54	270	26	160	30	10.9
					Well Site No. W2-D							
W2-D**	7/77		8.1	1050	810	205	115	475	10	830	570	10.8

*A is recharge and B is discharge.

**Temporary wells in the northern portion of the Watershed in agricultural areas. 'A' wells were located along the main branch of the Menomonee River, 'B' wells along the Little Menomonee River and 'C' and 'D' wells along smaller branches located in the northwestern portion of the Watershed.

Table I-B-2. Metal content of groundwater

Well No.	Date	µg/L			
		Cd	Cu	Pb	Zn
W2-3*	10-2-76	--	4	<3	2000
W6-4	"	--	<3	<3	50
W7-1*	"	--	3	<3	2200
W7-2	"	--	13	<3	110
W7-3	"	--	3	<3	20
W12-2*	"	--	5	<3	1400
W13-1*	"	--	<3	<3	5900
W13-3*	"	--	<3	<3	2400
W13-4	"	--	16	<3	110
W1-1	10-31-76	<0.2	5	<3	<20
W1-3*	"	<0.2	<3	<3	4700
W2-2	"	<0.2	<3	<3	100
W2-3*	"	<0.2	7	<3	1260
W3-2*	"	0.9	9	<3	1230
W5-1	"	<0.2	<3	<3	<20
W5-2	"	<0.2	<3	<3	<20
W6-1*	"	2.3	70	<3	8440
W6-2	"	1.5	59	3	1660
W10-1*	"	<0.2	6	<3	370
W14-1	"	<0.2	4	3	<20

*Galvanized pipe. Zinc values elevated due to zinc contamination from pipe.

Table I-8-3. Cation/anion percentages

	$SO_4^=$		Ca^{++}		Mg^{++}		$HCO_3^- + CO_3^=$		$Na^+ + K^+$		Cl^-		Cation/anion percentages						
Well No.	mg/L	me/L	mg/L	me/L	mg/L	me/L	mg/L	me/L	mg/L	me/L	mg/L	me/L	%Ca	%Mg	%Na	%SO₄	%HCO₃	%Cl	TDS
2-3	225	4.68	95	4.74	79	6.50	200	6.56	82	3.55	130	3.66	32	44	24	31	44	25	700
5-1	75	1.56	58	2.90	55	4.56	180	5.90	20	.85	34	.96	35	55	10	19	70	11	385
5-3	170	3.54	59	2.97	39	3.20	74	2.43	239	10.43	430	12.12	18	19	63	20	13	67	1200
8-2	76	1.58	228	6.35	59	4.82	300	9.84	21	.90	32	.90	53	40	7	13	80	7	500
9-1	160	3.33	153	7.64	66	5.43	290	9.51	30	1.30	32	.90	53	38	9	27	70	7	645
10-1	145	3.02	97	4.84	32	2.61	116	3.80	11	.50	14	.39	61	33	6	42	53	5	545
14-1	130	2.70	154	7.65	42	3.44	270	8.85	7	.31	8	.22	67	30	3	23	75	2	510
1-3	140	2.91	254	12.43	69	5.65	425	13.93	87	3.80	110	3.10	57	26	17	15	70	15	845
2-3	165	3.43	154	7.68	39	3.21	230	7.54	68	2.95	140	3.95	55	23	27	23	51	26	745
6-4	105	2.18	85	4.23	49	4.05	180	5.90	38	1.67	70	1.98	43	41	17	22	59	19	490
7-4	143	2.98	193	9.63	35	2.91	315	10.33	176	7.65	270	7.61	48	14	38	14	49	36	990
7-5	83	1.73	175	8.73	35	2.84	300	9.84	92	4.03	135	3.81	56	18	26	11	64	25	625
11-2	120	2.50	169	8.41	93	7.65	415	13.60	130	5.69	205	5.78	37	35	26	11	62	26	805
13-3	120	2.50	140	7.01	39	2.95	260	8.52	41	1.80	39	1.10	60	25	15	21	70	9	510
13-4	178	3.7	189	9.4	88	7.3	390	12.8	59	2.3	70	2.0	50	38	12	20	69	11	755
1-1	87	1.8	67	3.4	56	4.6	162	5.3	222	9.8	275	7.8	19	26	55	12	36	52	1095
1-2	110	2.3	106	5.2	59	4.8	234	7.8	157	6.8	230	6.5	31	29	40	14	47	39	995
1-4	82	1.7	42	2.0	29	2.4	105	3.5	89	4.7	34	1.0	22	26	52	27	57	16	395
2-1	920	19.2	336	16.0	135	11.2	330	11.0	38	1.5	58	1.6	57	38	5	60	35	5	1920
2-2	370	7.7	195	9.8	75	6.2	275	9.2	230	9.8	370	10.4	38	24	38	28	34	38	1590
3-2	280	5.8	113	5.6	95	7.8	233	7.6	34	1.4	180	5.1	38	53	9	31	41	27	1180
5-4	180	3.8	133	6.6	62	5.2	176	5.8	212	9.2	430	12.1	31	25	43	18	27	56	1380
6-1	125	2.6	69	3.4	47	3.8	163	5.4	36	1.5	70	2.0	39	44	17	26	54	20	625
6-2	135	2.8	121	6.0	46	3.8	187	6.2	75	3.2	170	4.8	46	29	24	20	45	35	930
7-1	74	1.5	47	2.4	24	2.0	125	4.2	53	2.3	50	1.4	36	30	34	21	59	20	420
7-2	105	2.2	90	4.4	40	3.2	202	6.8	142	6.1	175	4.9	32	23	45	16	49	35	745
13-1	165	3.4	99	5.0	56	4.6	205	6.8	80	3.4	80	2.3	38	35	26	27	54	18	790
13-2	200	4.2	110	5.4	53	4.4	181	6.0	93	3.9	105	3.0	39	32	29	32	45	23	895

*me/L is milliequivalent per litre.

Table I-8-4. Groundwater (GW) and surface water (SW) quality

Parameters	Donges Bay		Appleton Ave.		Pilgrim Rd.		124th St.		70th St.		Underwood		Honey	
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
						September 1976 to November 1976								
Specific cond. µmhos/cm	599 ±40	1350	538 ±65	1395 ±653	753 ±85	855 ±243	1162 ±246	1701 ±496	918 ±167	1923 ±233	960 ±162	830 ±65	676 ±120	900
Total dissolved solids, mg/L	583 ±92	600	493 ±121	887 ±510	598 ±20	660 ±177	971 ±72	900 ±85	766 ±56	1825 ±247	800 ±100	580 ±171	574 ±89	800
Alkalinity mg $CaCO_3$/L	285 ±12	220	202 ±43	181± 92	255 ±21	285 ±10	258 ±13	344 ±60	232 ±19	330 ±30	212 ±21	260 ±87	194 ±15	350
Chloride, mg/L	38 ±2	4	59 ±15	257 ±220	116 ±11	86 ±44	211 ±60	220 ±103	171 ±9	216 ±189	150 ±41	66 ±19	84 ±49	100
NO_3-N, mg/L	.91 ±.24	<.0.	.05 ±.04	<.02	.41 ±.67	.01 ±.01	3.5 ±.6	<.02	1.2 ±.6	<.02	--	<.02	.15 ±.13	<.02
NH_3-N, mg/L	.43 ±.18	.15	.07 ±.05	.22 ±.11	.06 ±.04	.11 ±.07	1.60 ±.83	.45 ±.27	.32 ±.50	.22 ±.02	.07 ±.10	.04 ±.03	.09 ±.08	.3
Dissolved reductive phosphorus, mg/L	.02 ±.01	.005	.01 ±.00	.008 ±.003	.07 ±.06	.009 ±.004	.84 ±.25	.170 ±.27	.19 ±.13	.013 ±.009	.01 ±.01	.01 ±.00	.04 ±.02	.02
Total phosphorus mg/L	--	--	.06± .02	--	.12 ±.06	--	1.05 ±.27	--	.31 ±.16	--	.09 ±.06	--	.10 ±.03	--
Stage (elevation) meters	221.76 ±.03	221.88 ±.06	213.18 ±.03	213.06 ±.02	230.49 ±.02	226.00 ±.27	214.30 ±.05	212.91 ±.77	192.61 ±.01	192.62 ±.54	--	--	--	--
						December 1976 to February 1977								
Cond µmhos/cm	505 ±35	890	1495 ±360	1162 ±612	753 ±40	811 ±306	1150 ±50	1407 ±398	1060 ±204	2120 ±715	850 ±57	981 ±530	2010 ±530	1064 ±780
Total dissolved solids, mg/L	613 ±82	610	1558 ±279	950 ±250	713 ±62	815 ±163	1123 ±99	1092 ±138	1165 ±163	1750 ±353	947 ±52	775 ±25	2063 ±646	1360 ±343
AIK $CaCO_3$, mg/L	282 ±65	280	322 ±58	166 ±88	315 ±23	300 ±20	328 ±34	360 ±42	271 ±10	435 ±21	265 ±33	325 ±26	1025 ±170	400 ±20
Chlor, mg/L	36 ±2	15	502 ±315	365 ±225	143 ±21	153 ±53	330 ±29	377 ±108	377 ±128	325 ±260	208 ±4	103 ±32	374 ±40	255 ±80
NO_3-N, mg/L	1.90 ±.16	<.02	.22 ±.22	.22 ±.46	2.05 ±.47	1.34 ±1.23	2.33 ±1.81	<.02	.72 ±.57	.01 ±.02	.32 ±.11	<.02	.27 ±.18	[illegible]
NH_3-N, mg/L	.14 ±.08	.25	.100 ±.064	.31 ±.23	.91 ±.94	.17 ±.11	8.45 ±2.90	.37 ±.11	2.43 ±1.96	.26 ±.16	.31 ±.04	.15 ±.05	.52 ±.67	[illegible]
DRP-P, mg/L	.015 ±.050	.026	.025 ±.035	.20 ±.38	.043 ±.049	.02 ±.03	1.02 ±.25	.01 ±.01	.36 ±.17	.006 ±.003	.015 ±.007	.01 ±.00	.03 ±.02	[illegible]
TP-P, mg/L	.085 ±.015	--	.03 ±.04	--	.133 ±.045	--	1.25 ±.21	--	.57 ±.19	--	.16 ±.13	--	.18 ±.21	--
Stage (elevation) meters	221.95 ±.23	221.89 ±.09	212.58 ±.55	212.57 ±.50	231.14	226.31 ±.53	214.38	213.93 ±.27	192.74	192.76 ±.17	--	--	--	--

PART II

POTENTIAL IMPACTS FROM LAND USE ACTIVITIES

by

R. N. HOFFER
M. P. ANDERSON

ABSTRACT

A wide range of land uses in the Menomonee River Watershed have been examined for their potential to degrade surface water quality through groundwater discharge. Excessive amounts of dissolved chloride derived from road runoff is believed to have caused the most dramatic change in groundwater quality over pre-urbanized conditions. Fertilizer and pesticide applications on cropland, effluent from septic tanks and sewer line leakage are suspected as possible sources of contaminants on some portions of the Watershed. Solid waste disposal areas probably represent a comparatively local rather than regional hazard. Seepage from barnyards, salt storage areas, industrial wastewater disposal sites, municipal sewage sludge spreading areas and air pollutant fallout are believed to have minor impacts.

A series of 17 maps has been prepared evaluating the relative contaminant potential for different areas in 9 major land use categories. This approach optimizes the interpretation of water quality data and provides guidance for locating future study sites. Investigations at other watersheds can proceed more efficiently if the experiences and recommendations of this research in the Menomonee River Watershed are considered.

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II-1. INTRODUCTION

One of the goals of the Menomonee River Pilot Watershed study was to investigate some of the complex relationships between land use and surface water quality. While the largest source of contaminants to the river system originates from direct point and non-point surface discharge, significant pollutant loadings potentially could be discharged to the river in groundwater. Specifying in detail the importance of contaminants transported to the river in groundwater is necessary to obtain a reasonable understanding of the Watershed under present and probable future levels of development. This portion of the project was directed toward obtaining data which are useful in identifying those areas of the Watershed where land use activities could have an impact on groundwater which discharges to the Menomonee River System. Subtasks incorporated in this section of the project include:

a. Identifying those land uses which potentially could affect groundwater quality;

b. identifying which of those activities are currently being practiced in the Watershed and where they are located;

c. relating operational history to geological and hydrological factors for the use areas;

d. developing a methodology to rank the potential for contaminants to be transported to surface waters by subsurface flow;

e. using the methodology to prepare maps showing contaminant potentials for various land use activities in the watershed;

f. relating this comparative analysis to in-field water quality data; and

g. developing recommendations for additional study in the basin and for future investigations in other watersheds.

The contaminant potential maps included as Figs. II-1 to II-17, represent the principal final product of the analysis. As a supplement to these are sections on methods of study, data analysis and interpretation for each land use category, final recommendations, conclusions and supportive appendices.

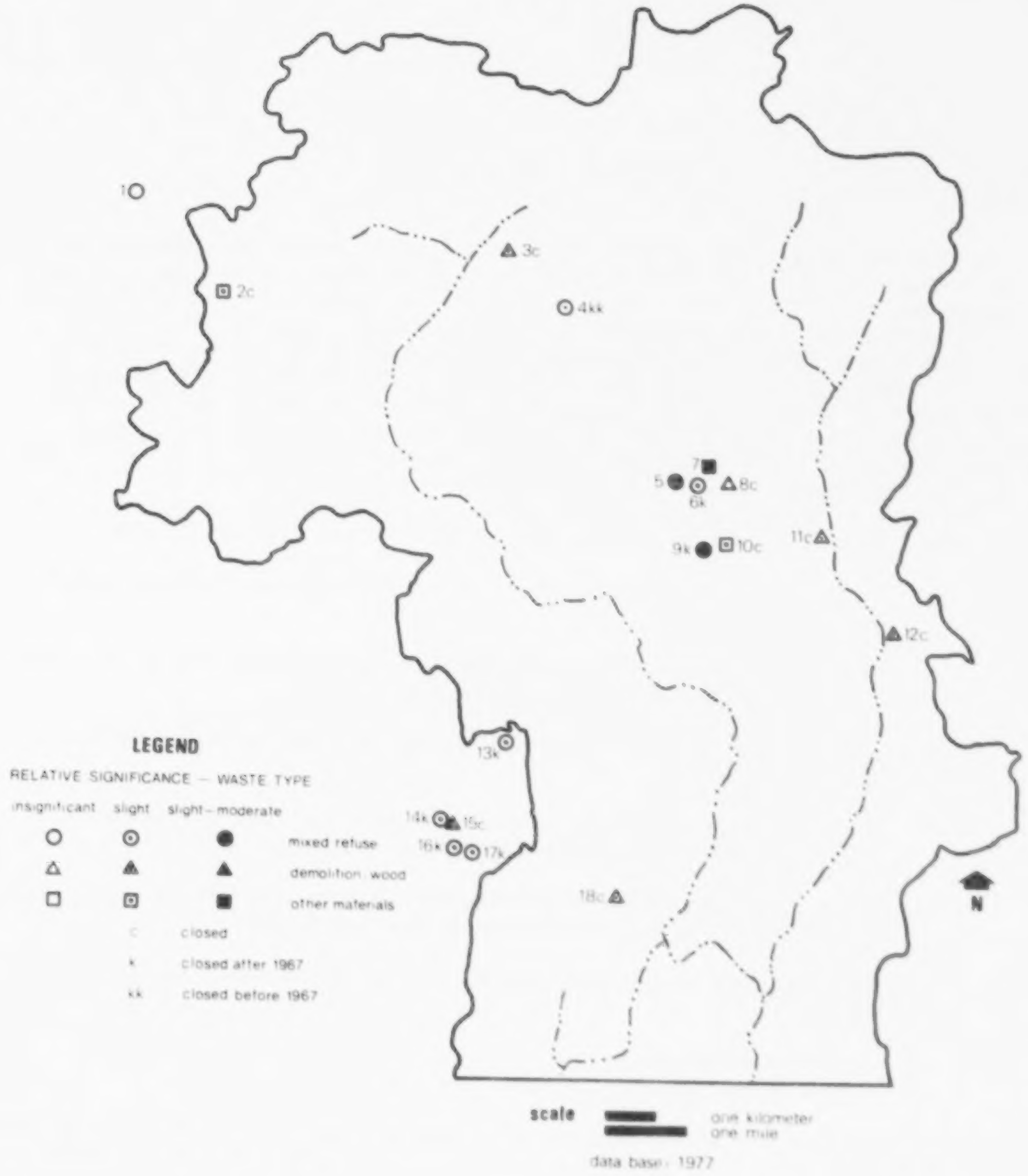
1
2c
3c
4kk
5
6k
7
8c
9k
10c
11c
12c
13k
14k
15c
16k
17k
18c
LEGEND
RELATIVE SIGNIFICANCE — WASTE TYPE
insignificant
slight
slight–moderate
mixed refuse
demolition wood
other materials
c closed
k closed after 1967
kk closed before 1967
N
scale
one kilometer
one mile
data base: 1977

Fig. II-1. Impact of solid waste disposal areas on the surface water quality of the upper portion of the Menomonee River Basin.

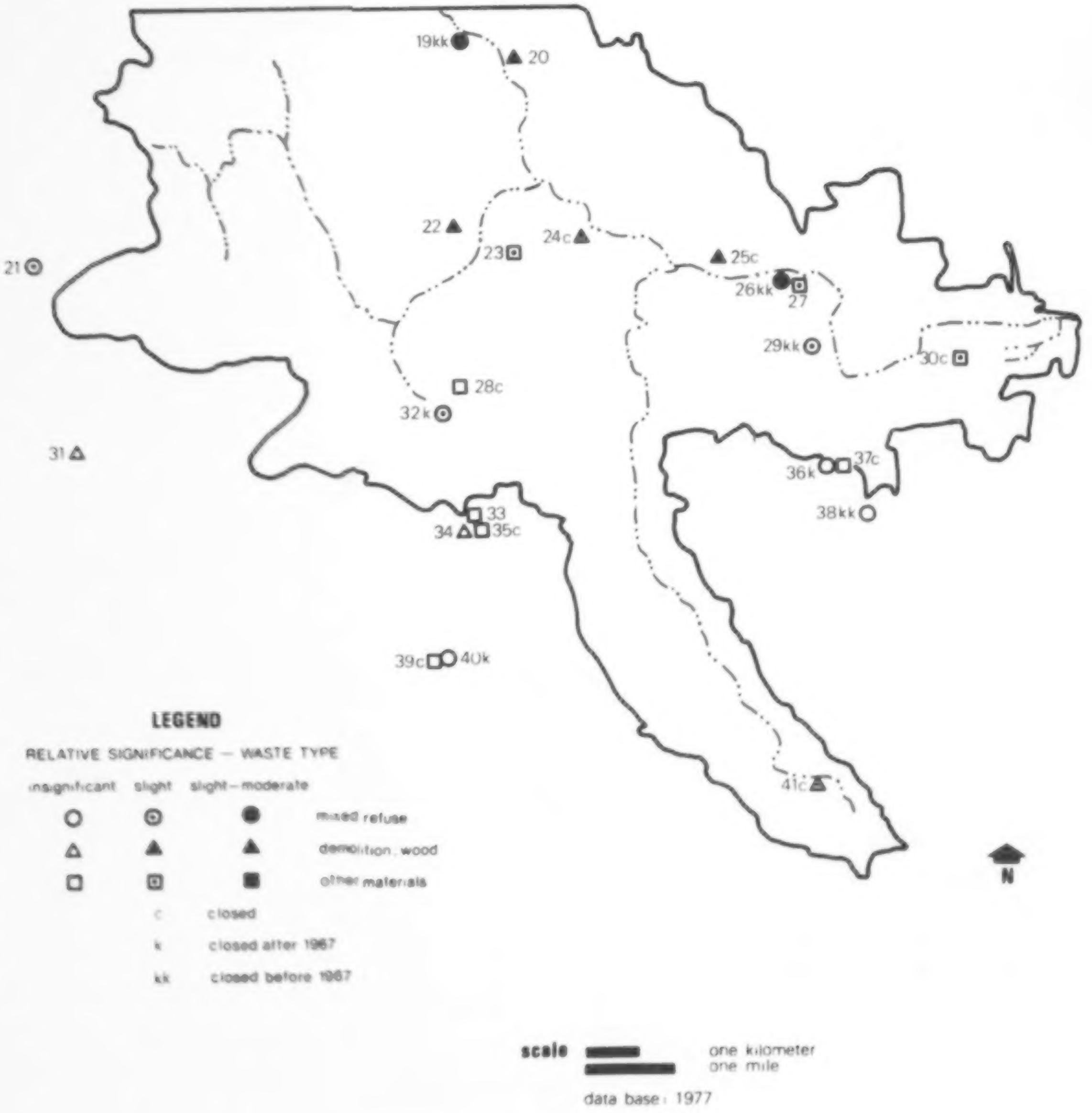
19kk
20
22
23
24c
25c
26kk
27
21
29kk
30c
28c
32k
31
36k
37c
38kk
33
34
35c
39c
40k
41c
LEGEND
RELATIVE SIGNIFICANCE — WASTE TYPE
insignificant
slight
slight – moderate
mixed refuse
demolition, wood
other materials
c closed
k closed after 1967
kk closed before 1967
N
scale
one kilometer
one mile
data base: 1977

Fig. II-2. Impact of solid waste disposal areas on the surface water quality of the lower portion of the Menomonee River Basin.

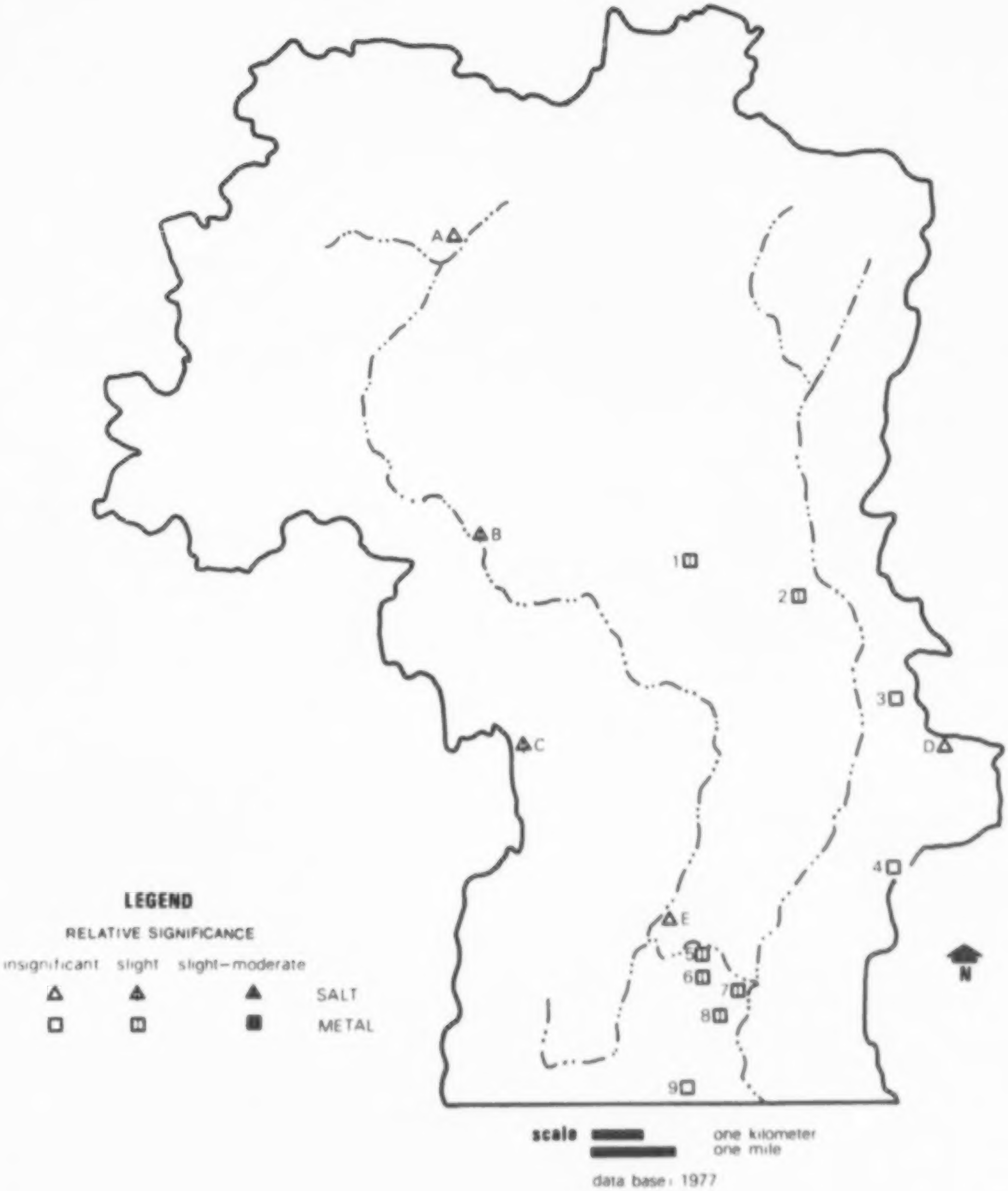
A
B
C
D
E
1
2
3
4
5
6
7
8
9
N
LEGEND
RELATIVE SIGNIFICANCE
insignificant
slight
slight–moderate
SALT
METAL
scale
one kilometer
one mile
data base: 1977

Fig. II-3. Impact of salt and metal storage areas on the surface water quality of the upper portion of the Menomonee River Basin.

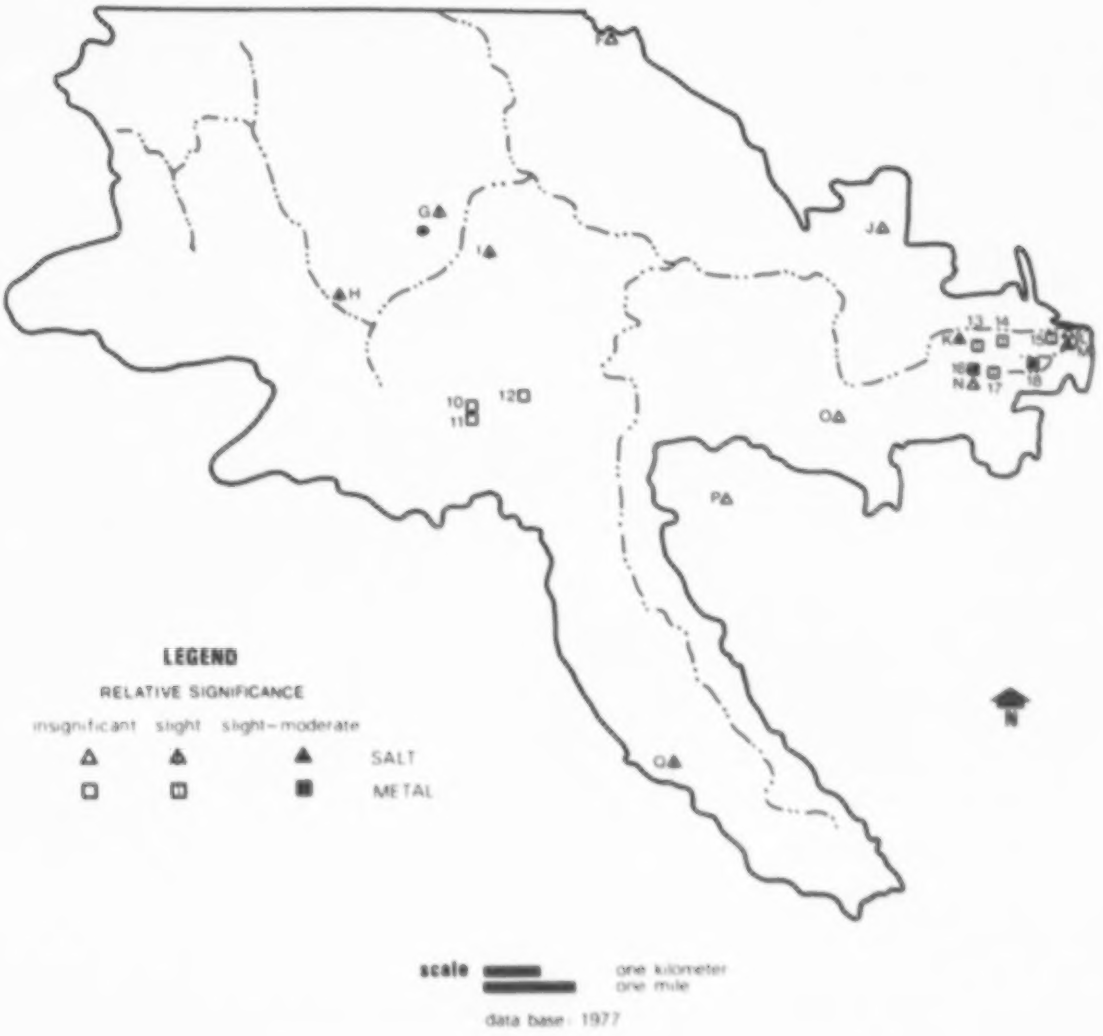
F
G
I
H
J
K
13
14
15
16
N
17
18
10
11
12
O
P
Q
LEGEND
RELATIVE SIGNIFICANCE
insignificant
slight
slight-moderate
SALT
METAL
N
scale
one kilometer
one mile
data base: 1977

Fig. II-4. Impact of salt and metal storage areas on the surface water quality of the lower portion of the Menomonee River Basin.

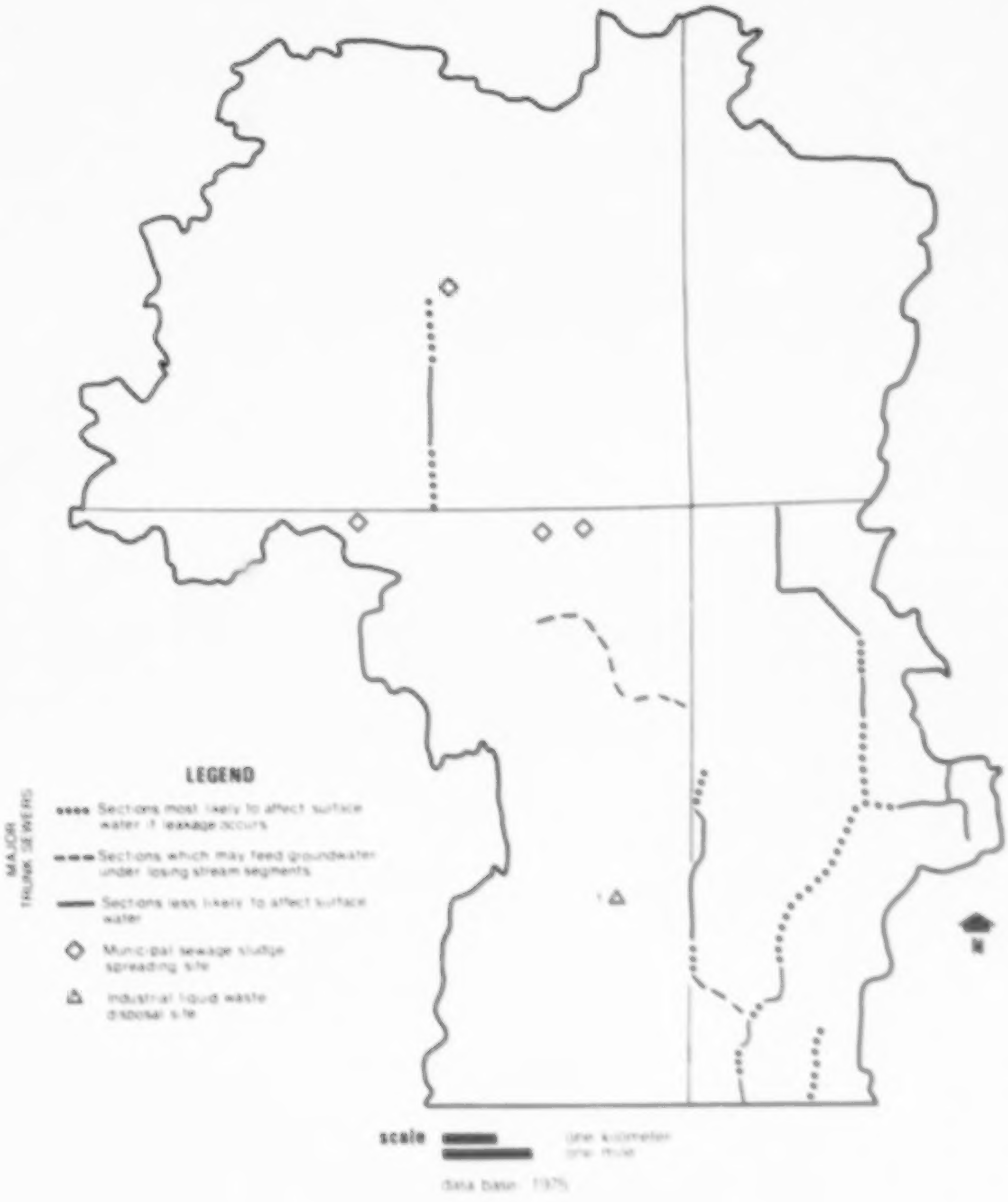
LEGEND
MAJOR TRUNK SEWERS
Sections most likely to affect surface water if leakage occurs
Sections which may feed groundwater under losing stream segments
Sections less likely to affect surface water
Municipal sewage sludge spreading site
Industrial liquid waste disposal site
N
scale
one kilometer
one mile
data base: 1975

Fig. II-5. Impact of liquid waste management on the surface water quality of the upper portion of the Menomonee River Basin.

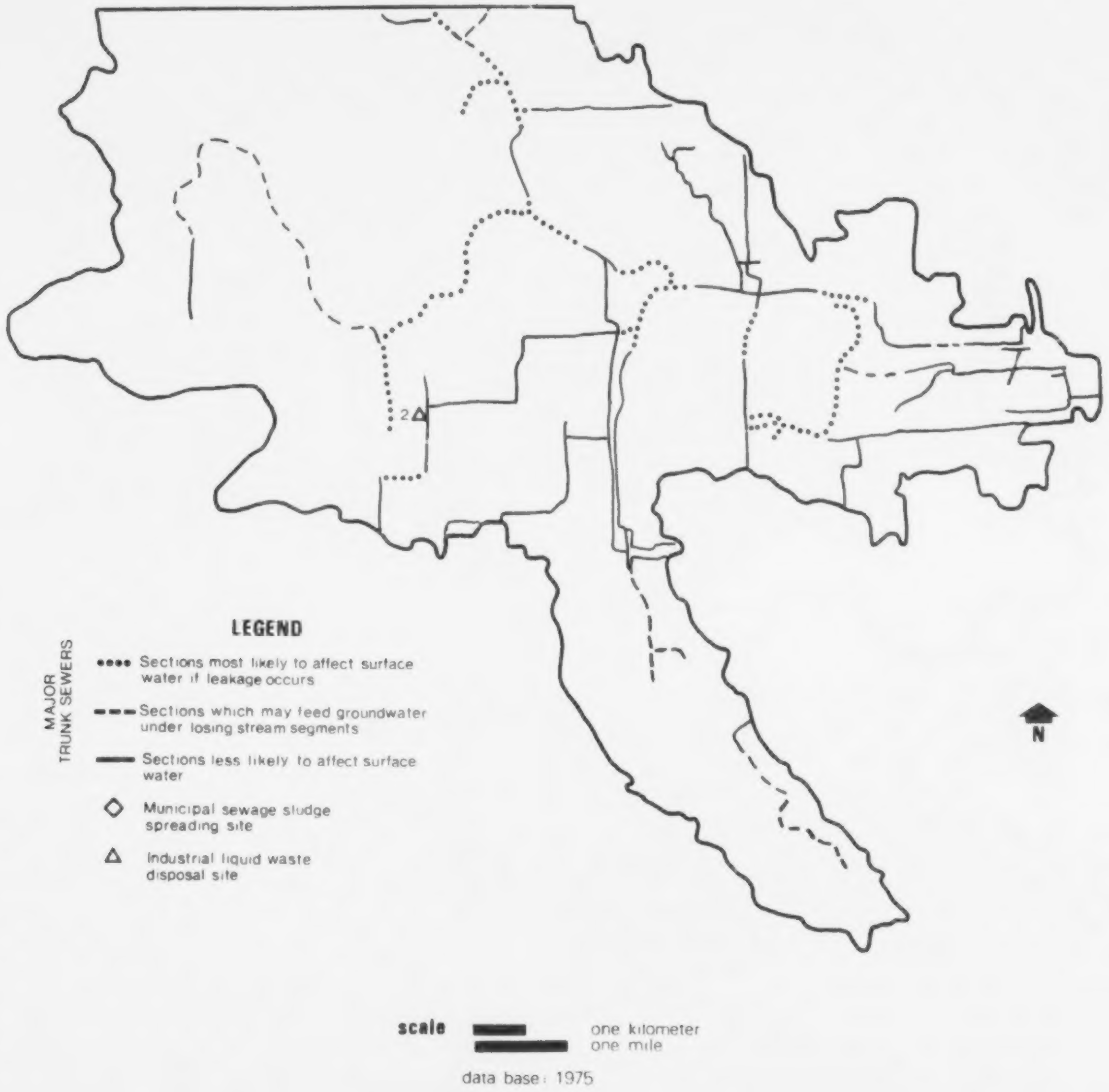
2△
LEGEND
MAJOR TRUNK SEWERS
•••• Sections most likely to affect surface water if leakage occurs
- - - Sections which may feed groundwater under losing stream segments
— Sections less likely to affect surface water
◇ Municipal sewage sludge spreading site
△ Industrial liquid waste disposal site
N
scale
one kilometer
one mile
data base: 1975

Fig. II-6. Impact of liquid waste management on the surface water quality of the lower portion of the Menomonee River Basin.

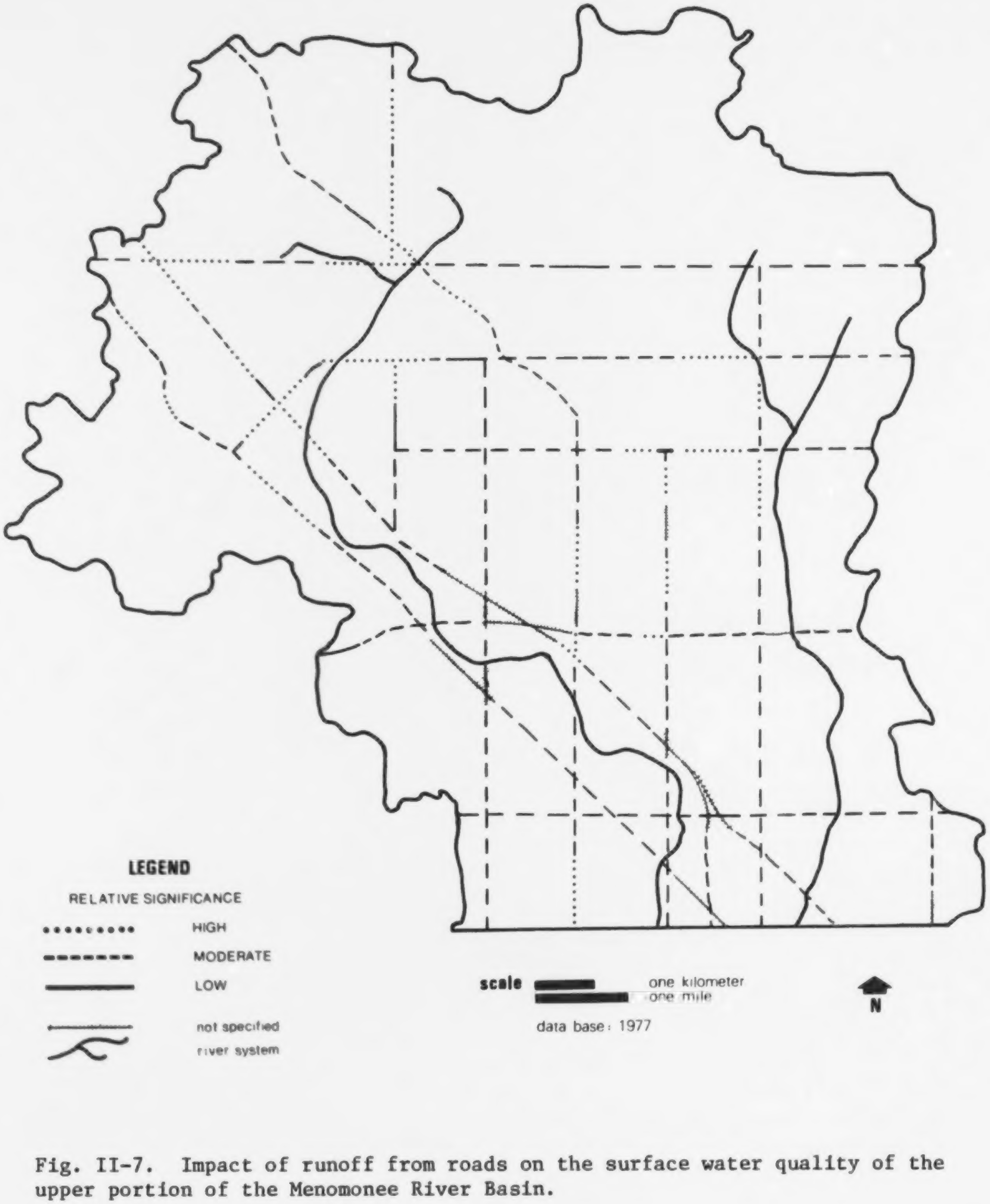
LEGEND
RELATIVE SIGNIFICANCE
HIGH
MODERATE
LOW
not specified
river system
scale
one kilometer
one mile
N
data base: 1977

Fig. II-7. Impact of runoff from roads on the surface water quality of the upper portion of the Menomonee River Basin.

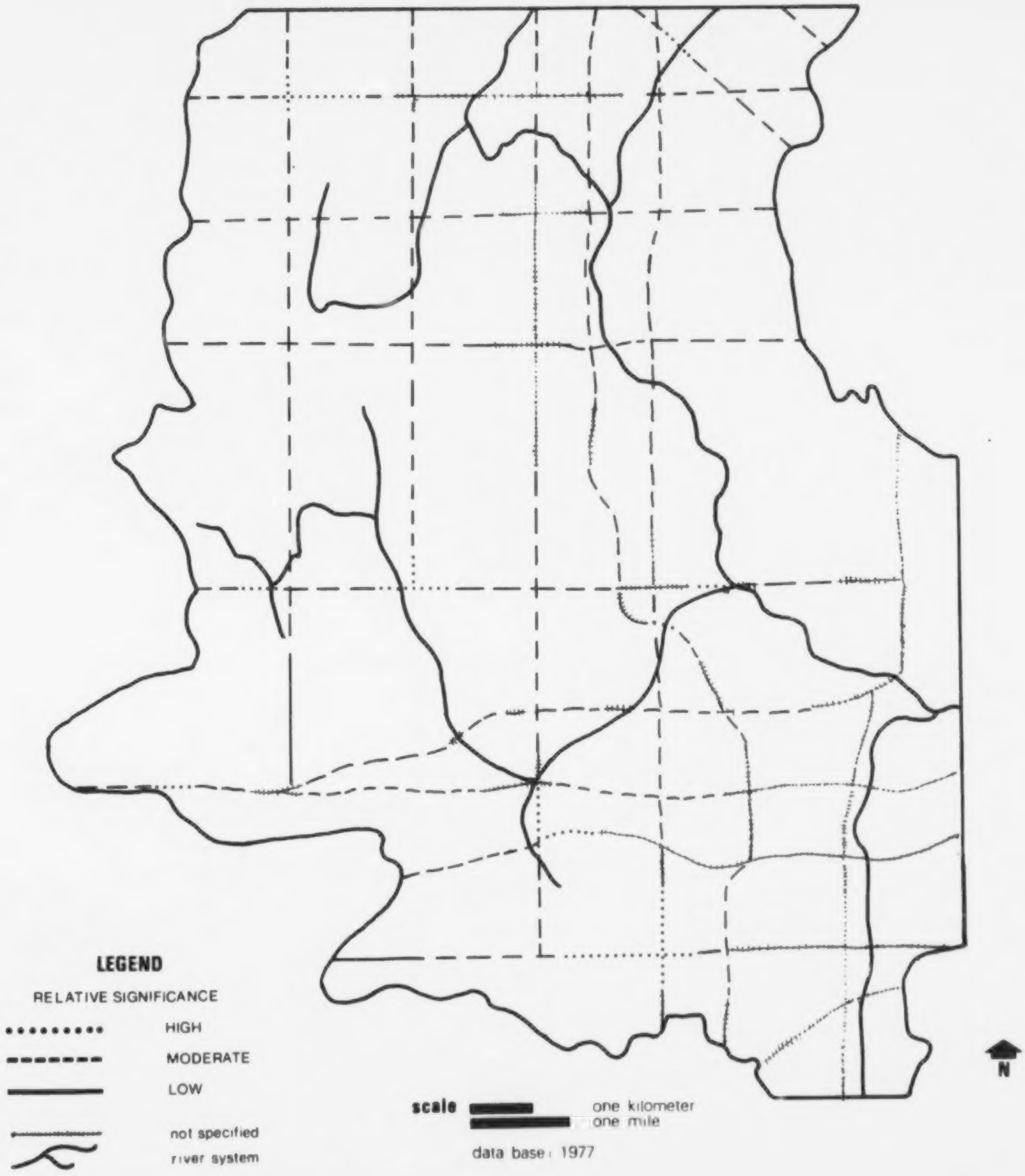
LEGEND
RELATIVE SIGNIFICANCE
HIGH
MODERATE
LOW
not specified
river system
scale
one kilometer
one mile
data base: 1977
N

Fig. II-8. Impact of runoff from roads on the surface water quality of the lower portion of the Menomonee River Basin.

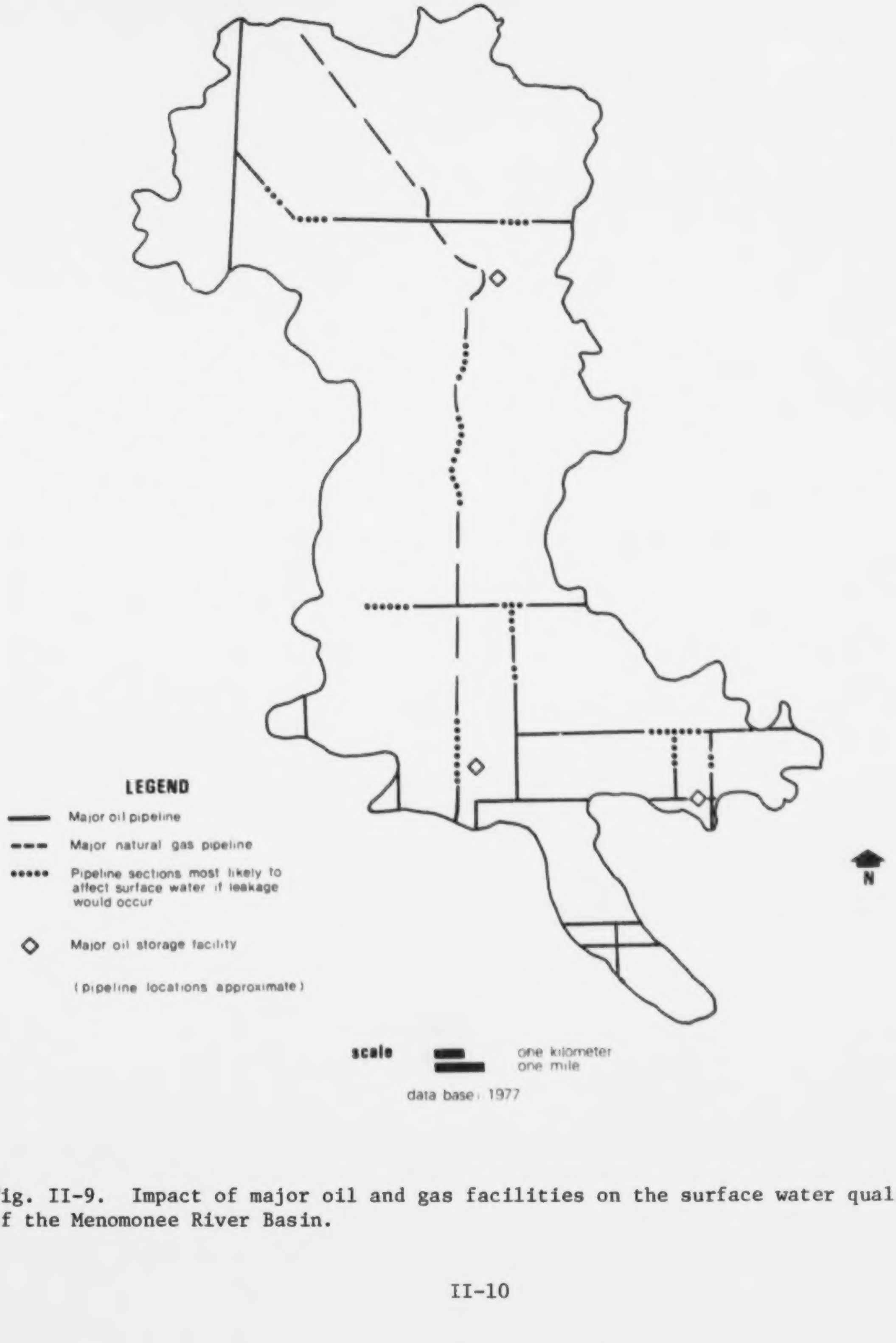
LEGEND
Major oil pipeline
Major natural gas pipeline
Pipeline sections most likely to affect surface water if leakage would occur
Major oil storage facility
(pipeline locations approximate)
N
scale
one kilometer
one mile
data base: 1977

Fig. II-9. Impact of major oil and gas facilities on the surface water quality of the Menomonee River Basin.

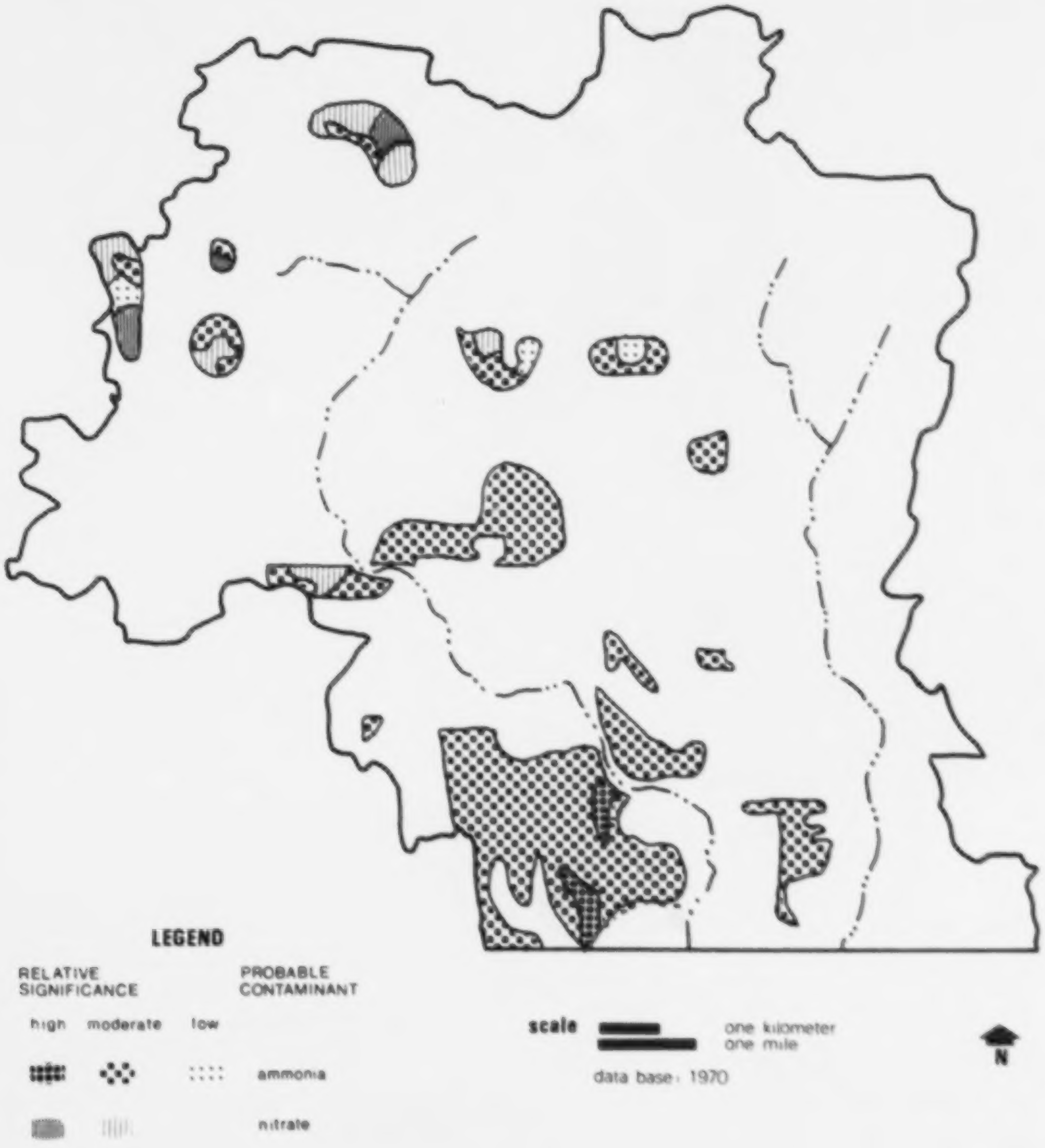
LEGEND
RELATIVE SIGNIFICANCE
PROBABLE CONTAMINANT
high
moderate
low
ammonia
nitrate
scale
one kilometer
one mile
data base: 1970
N

Fig. II-10. Impact of septic tanks on the surface water quality on the upper portion of the Menomonee River Basin. (See text, page II-31 for explanation of relative significance.)

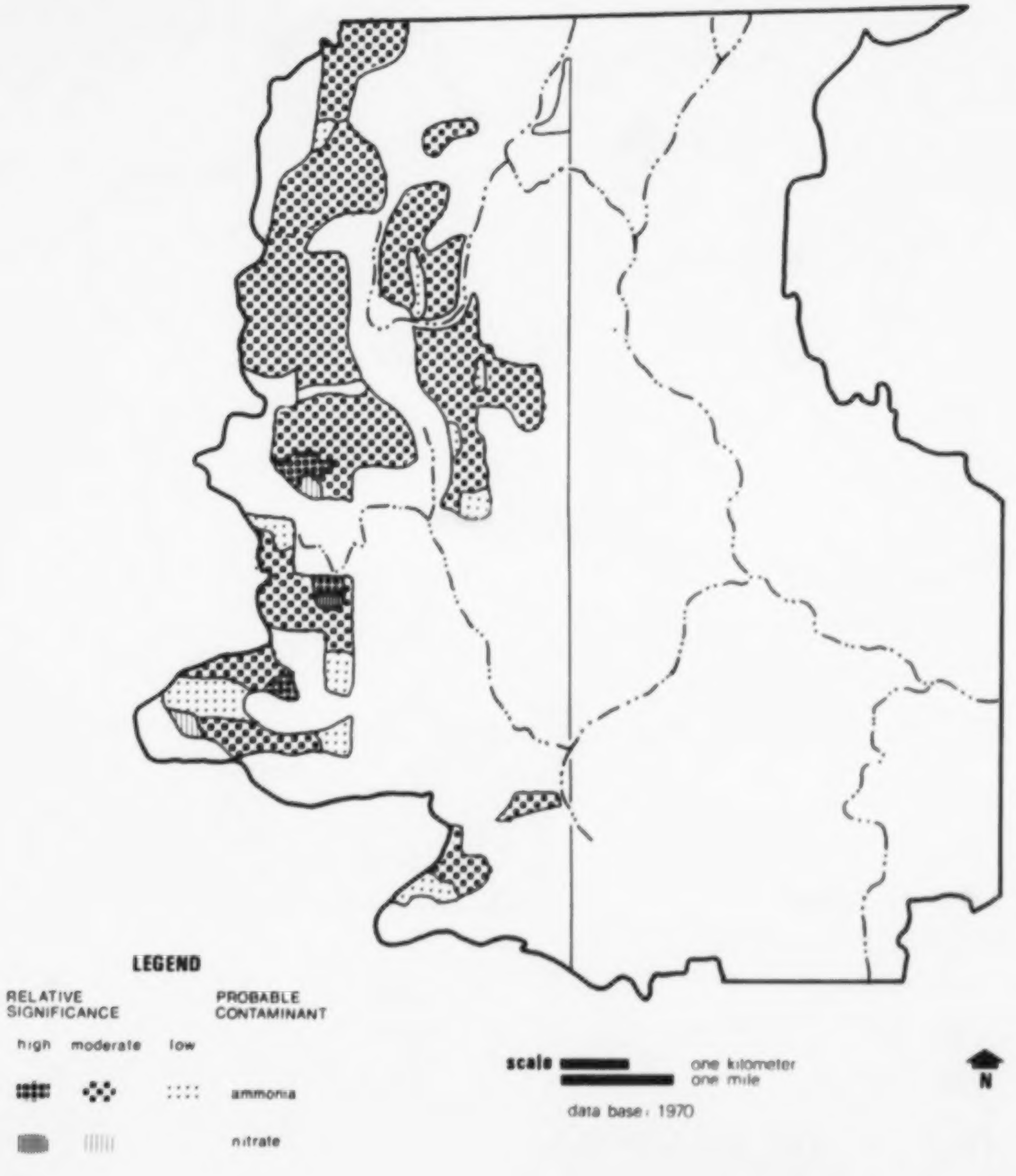
LEGEND
RELATIVE SIGNIFICANCE
PROBABLE CONTAMINANT
high
moderate
low
ammonia
nitrate
scale
one kilometer
one mile
data base: 1970
N

Fig. II-11. Impact of septic tanks on the surface water quality on the lower portion of the Menomonee River Basin.

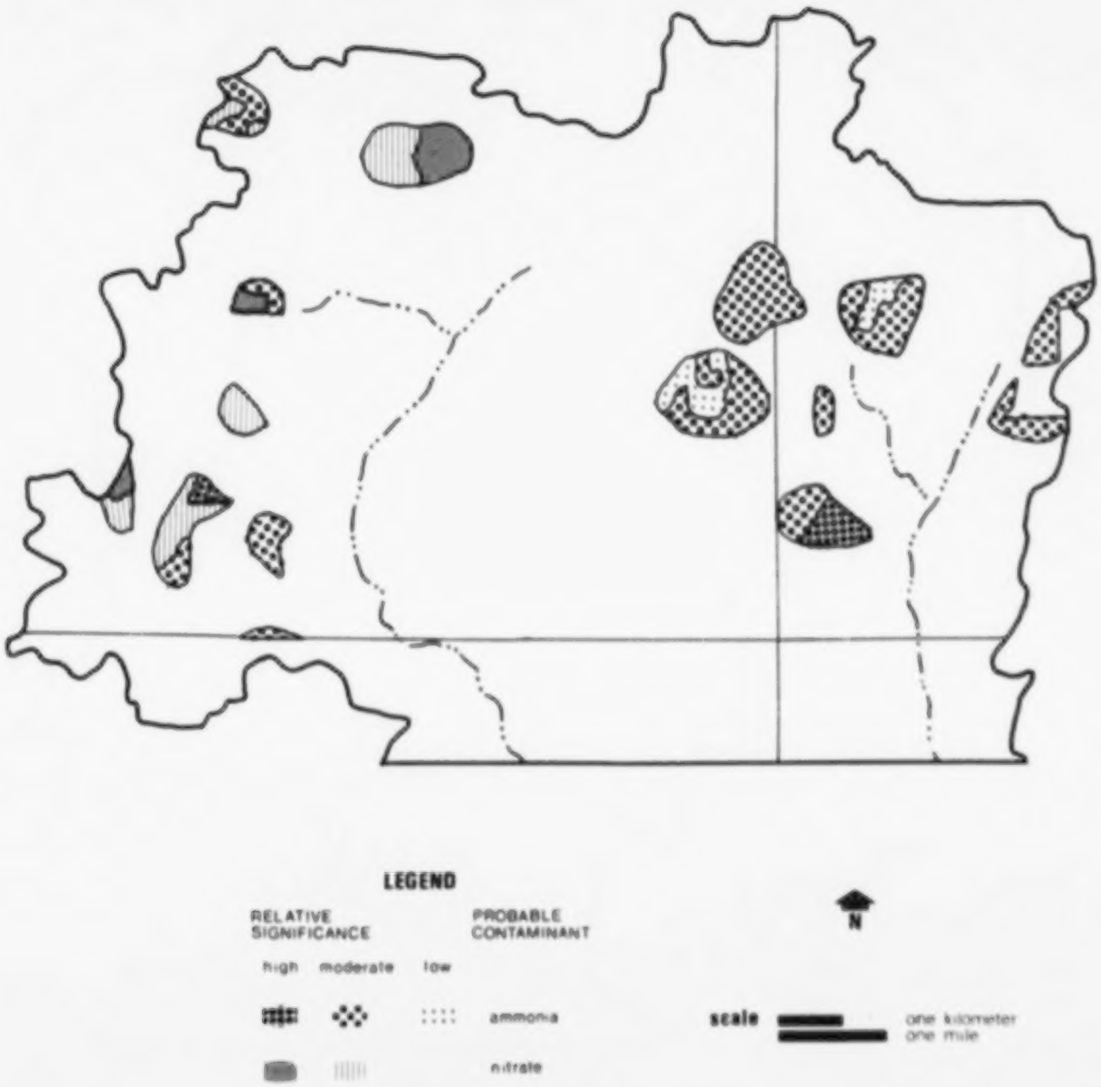
LEGEND
RELATIVE SIGNIFICANCE
PROBABLE CONTAMINANT
high
moderate
low
ammonia
nitrate
N
scale
one kilometer
one mile

Fig. II-12. Impact of septic tanks on the surface water quality on the upper portion of the Menomonee River Basin predicted for the year 2000.

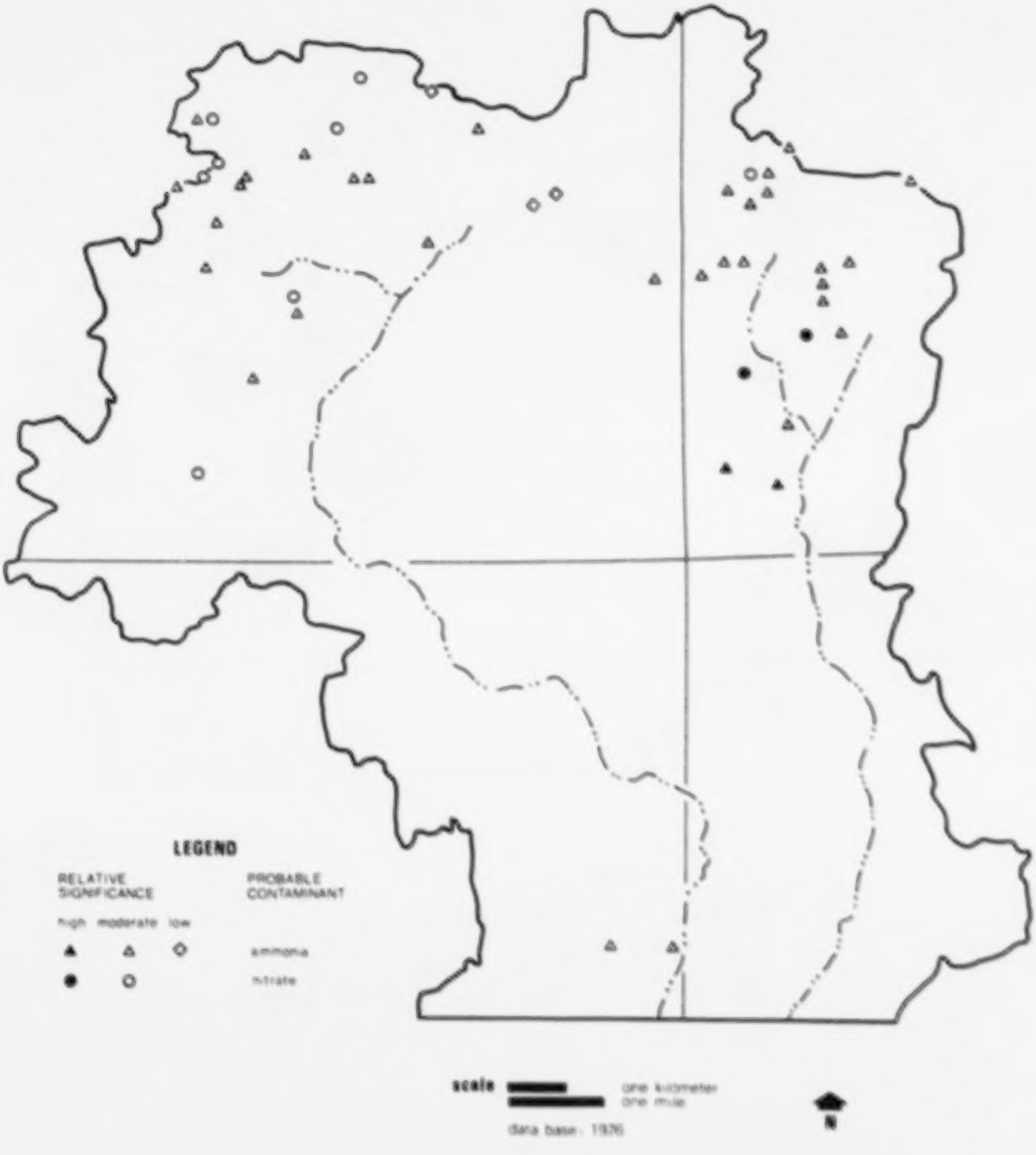
LEGEND
RELATIVE SIGNIFICANCE
PROBABLE CONTAMINANT
high
moderate
low
ammonia
nitrate
scale
one kilometer
one mile
data base: 1976
N

Fig. II-13. Impact of barnyards on the surface water quality of the Menomonee River Basin.

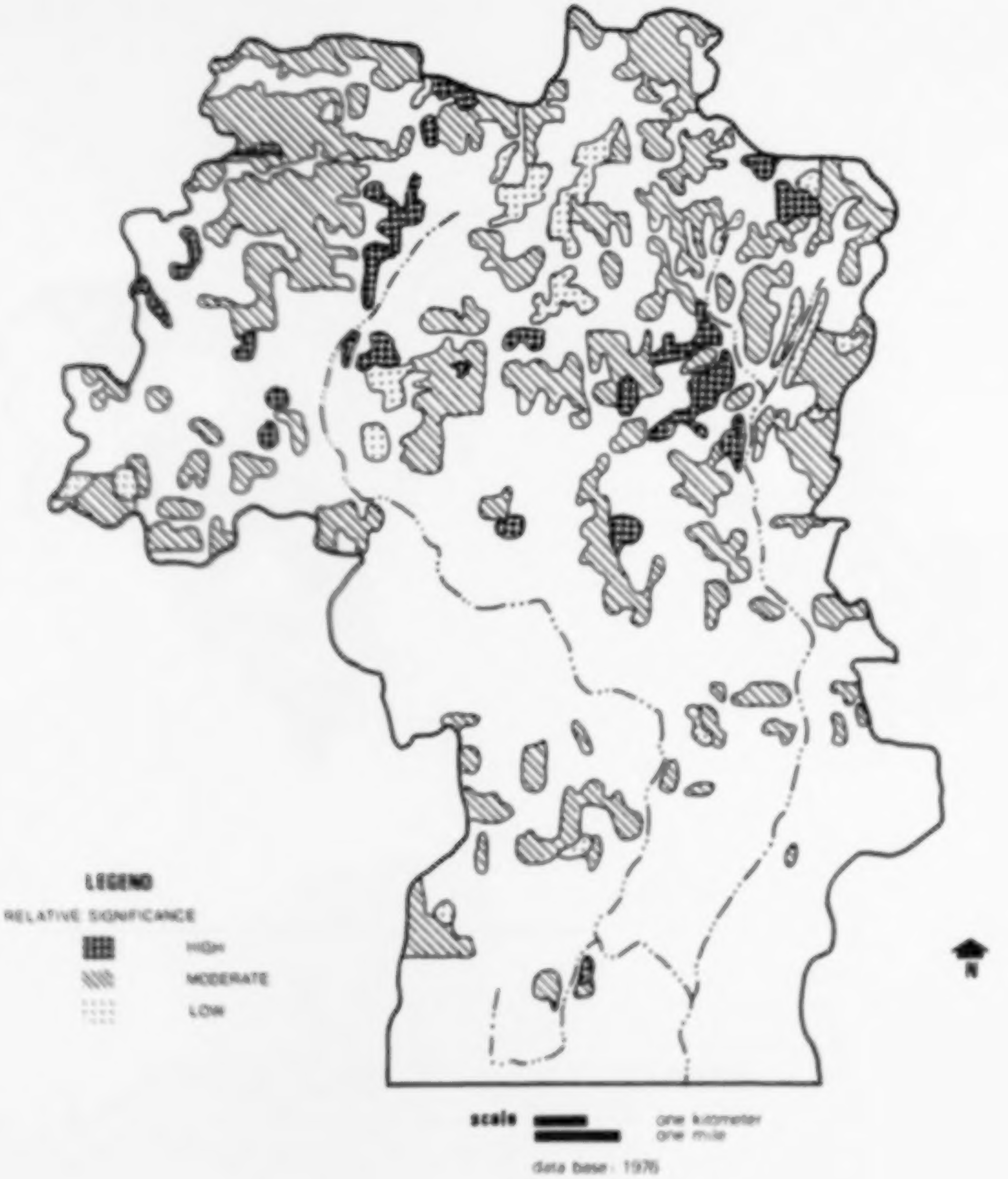
LEGEND
RELATIVE SIGNIFICANCE
HIGH
MODERATE
LOW
N
scale
one kilometer
one mile
data base: 1976

Fig. II-14. Impact of cropland on the surface water quality of the Menomonee River Basin.

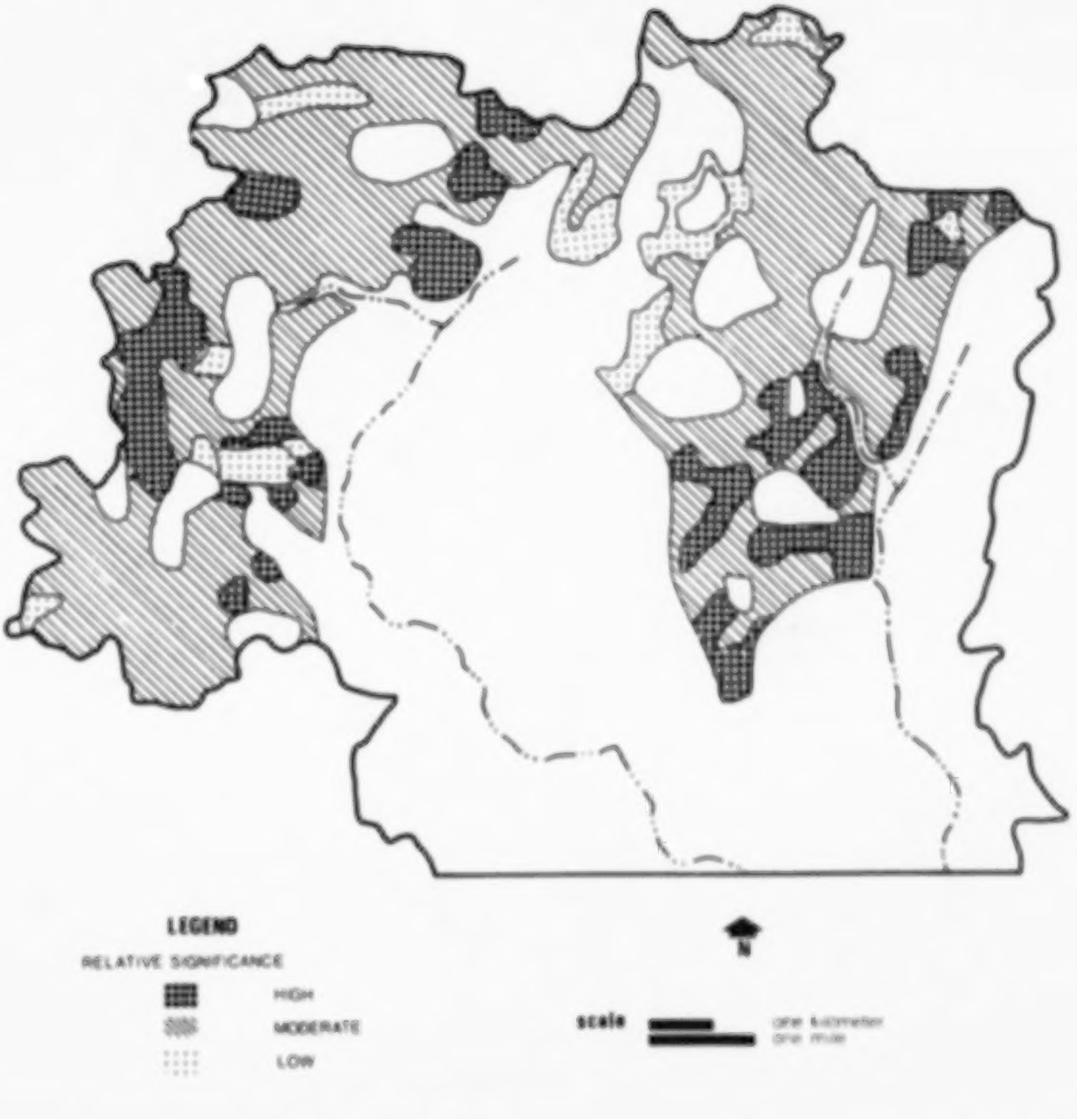
LEGEND
RELATIVE SIGNIFICANCE
HIGH
MODERATE
LOW
N
scale
one kilometer
one mile

Fig. II-15. Impact of cropland on the surface water quality of the Menomonee River Basin predicted for the year 2000.

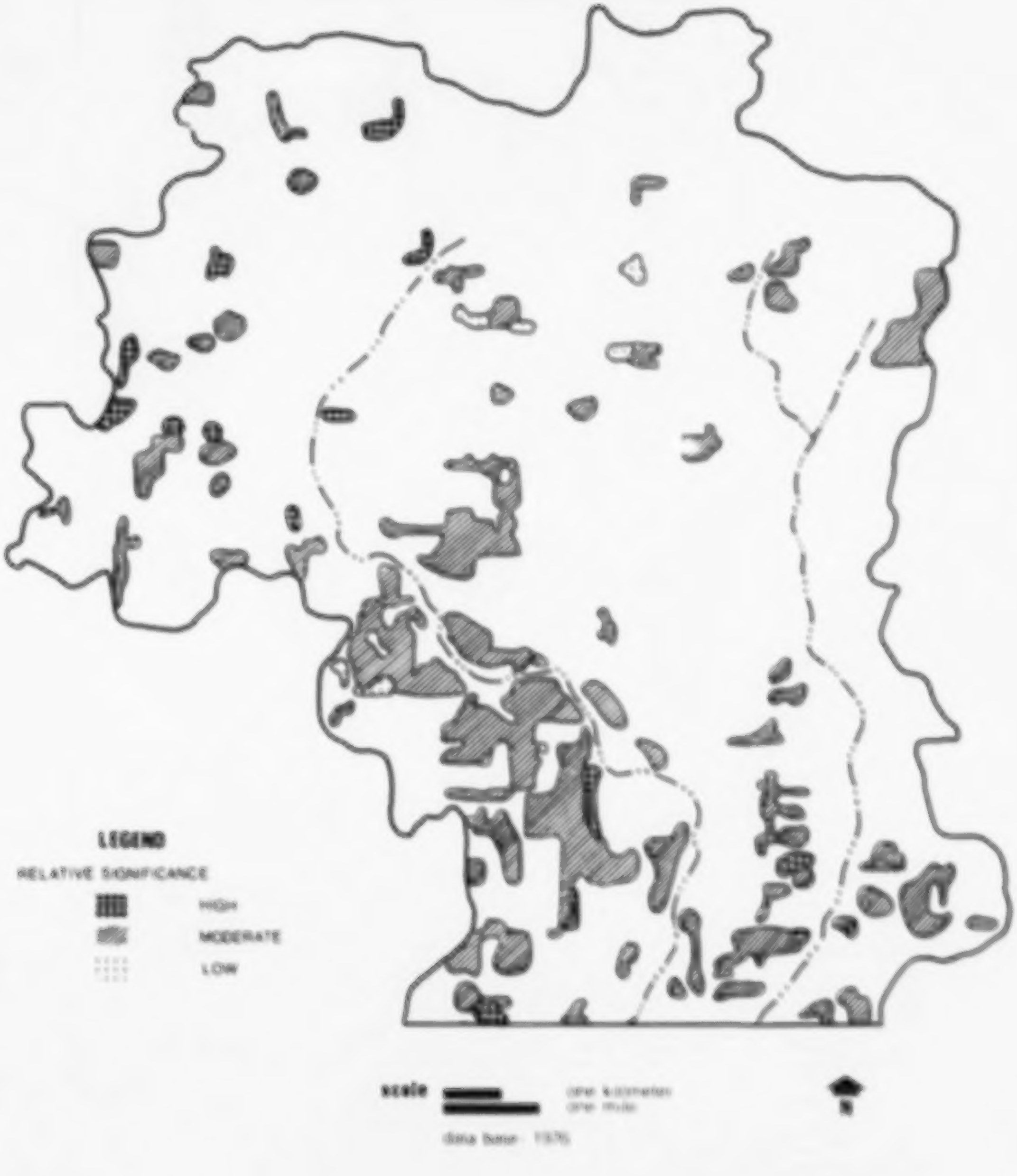
LEGEND
RELATIVE SIGNIFICANCE
HIGH
MODERATE
LOW
scale
one kilometer
one mile
N
data base - 1975

Fig. II-16. Impact of residential lawns on the surface water quality of the upper portion of the Menomonee River Basin.

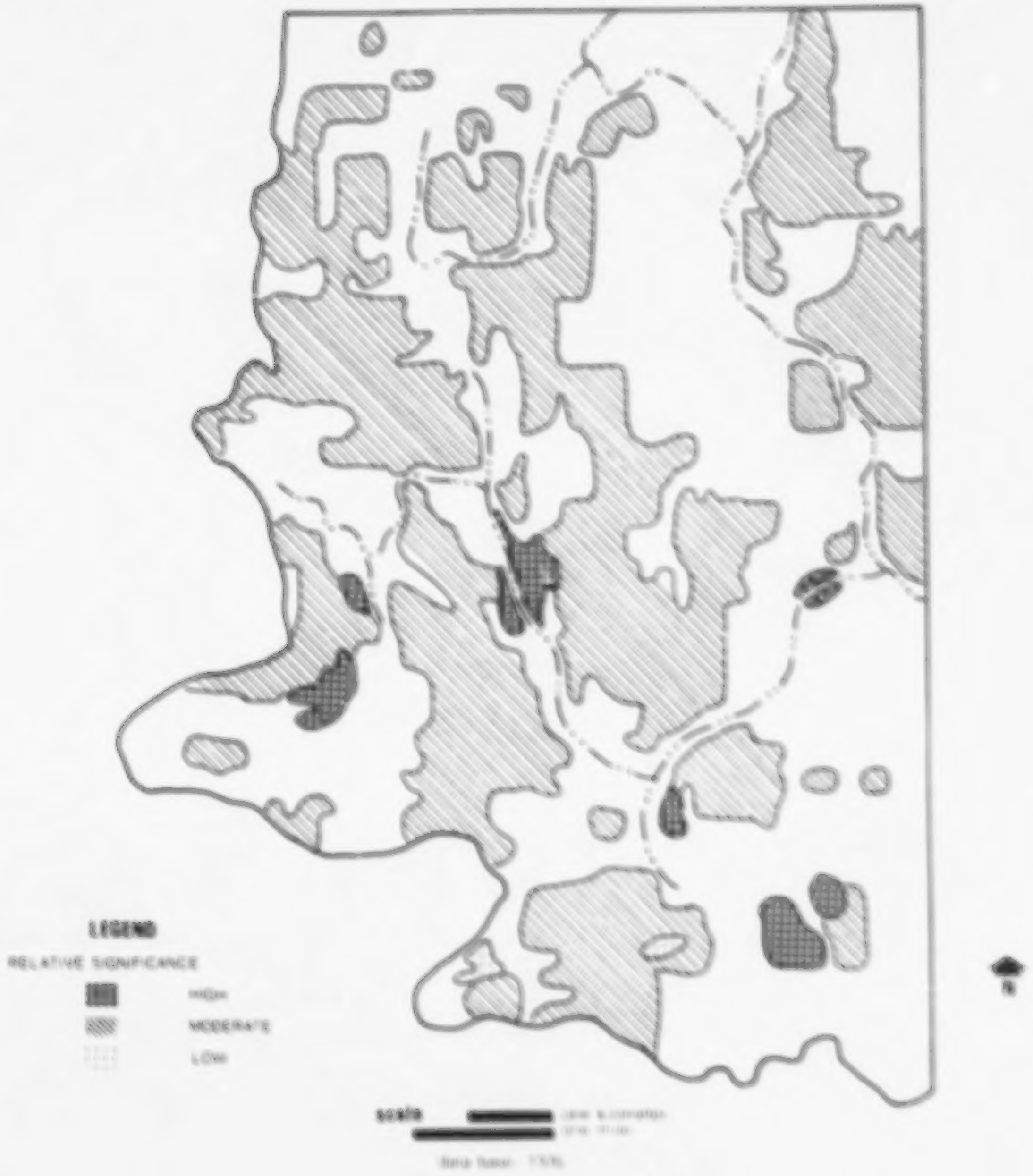
LEGEND
RELATIVE SIGNIFICANCE
HIGH
MODERATE
LOW
scale
N

Fig. II-17. Impact of residential lawns on the surface water quality of the lower portion of the Menomonee River Basin.

II-2. CONCLUSIONS

The overall quality of groundwater derived from unconsolidated materials discharging to the Menomonee River has been evaluated by Eisen (1) based on in-field monitoring data. Perhaps the most significant control on groundwater quality is the weathering of geologic materials. The goal of this phase of the groundwater study was to assess the potential impact of various land uses on groundwater which discharges to the Menomonee River System. However, certain trends can be related to the presence of specific land use categories in the Watershed. The application of road salts, with consequent runoff and aquifer recharge, is believed to be the cause of major, widespread modification of groundwater quality. Land uses suspected as factors in causing more subtle changes include fertilizer and pesticide applications on cropland, regional septic tank use, sewer line leakage and solid waste disposal practices. It should be stressed that the analyses presented in Figs. II-1 to II-17 represent a qualitative evaluation of land use and geologic settings rather than the outcome of comprehensive monitoring. The assessments are directed at understanding the role of contaminant transfer to surface waters by subsurface flow. It is likely that the relative importance of specific land uses in the immediate area of the use sites will be different from the syntheses presented here.

Despite the limitations inherent in this approach, the research has produced significant information relating land use and groundwater quality to surface water quality. The series of contaminant potential maps (Figs. II-1 to II-17) represents one of the first comprehensive attempts at understanding the variety of urban and rural land uses which can affect surface water quality through groundwater flow paths. A summary of what is believed to constitute the relative significance of various sources is included in Table II-1. There is considerable merit in following this approach in water resource management analyses. Assessments of other watersheds should be expedited by considering the recommendations outlined in this report.

Table II-1. Groundwater contributions to surface water quality for the Menomonee River Basin: potential impacts from land use activities

			Probable significance			Areal impact		Principal pollutants							
Rank	Use or other category	Assessment	Major	Inter.	Minor	Local	Regional	Cl	SO_4	Metals	Nitrogen	PO_4	Harmful bacteria	Hazardous organics	Hydrocarbons
1	Weathering of geologic materials	Impact assured	X				X	X	X						
2	Road runoff	"	X				X	X	X	X	X	X	X	X	X
3	Fertilizer and pesticide applications on croplands	Impact inter-preted		X			X				X	X		X	
4	Septic tanks	"		X			X	X			X	X			
5	Sewer line leakage	"		X		X	X	X			X	X	X		
6	Solid waste disposal areas	"		X	X	X		X	X	X	X			X	
7	Barnyards	"			X		X	X			X				
8	Salt storage areas	"			X	X		X							
9	Industrial wastewater disposal	"			X	X		X	X						X
10	Sewage sludge spreading	"			X	X		X		X	X	X			
11	Air pollutant fallout	"			X		X	X	X						
?	Metal storage areas	Impact unknown			X	X		X	X	X					X
?	Oil and gas facilities	"			X	X		X	X						X
?	Residential lawns	"		X	X		X				X	X		X	
?	Other users	"		?		?	?				?				

II-3. RECOMMENDATIONS

The Menomonee River Watershed was selected for study because it has exhibited a rapidly changing pattern of urbanization in a relatively small, definable area. Continued research in the Watershed is warranted. From a groundwater perspective, several different approaches can be taken. Three examples are:

a. To continue the thrust of the IJC goals, accelerated programs of in-field groundwater monitoring could be carried out at various land use sites. The relative ranking list provided as Table II-2 would be useful in developing priorities. Those uses whose impacts are unknown should also be examined. It is important that stations at major study sites be maintained over a period of several years because changes in the hydrogeologic regime occur at a comparatively slow rate.

b. Groundwater monitoring could be conducted as part of an overall program to control a specific pollutant problem in the river system. Assuming wastewater discharges are eliminated in the future, attention might be placed, for example, on reducing nutrient loadings in surface waters. This aim will necessitate monitoring some areas (i.e., septic tanks or croplands) while omitting others (i.e., salt and metal storage).

c. Interest might be raised in protecting portions of the bedrock aquifer most susceptible to groundwater contamination from the overlying unconsolidated materials. This need would warrant considering many land uses as to their local impacts on groundwater rather than, as was done in this program, on the eventual impact to surface waters.

The question remains as to how relationships between land use and groundwater discharge, which control surface water quality, can be optimally examined in other watersheds in the Great Lakes Basin. Although the various kinds of land use activities which can contribute to groundwater contamination have been identified for the Menomonee River Watershed, the relative importance of these activities may be considerably different in other watersheds undergoing development. These differences could be due to differences in geology, groundwater use or areal distribution of land uses. Thus, based on our experience in this project a typical sequence of steps which might be useful in evaluating sources of contamination in other watersheds include:

a. Compile the available land use and hydrogeologic data for the area.

b. Identify the aquifers which are hydraulically connected, with surface waters.

Table II-2. Composition of soil extracts

Sampling location	Location		Parameter, mg/L			
	Figure No.	Site No.	Cl	SO_4	N	Hardness
Within 6 m of salt storage pile	II-4	H	6200	80	--	720
Within 6 m of salt storage pile	II-4	Q	3000	200	--	1200
In drainage ditch below salt storage pile	II-4	Q	2400	120	--	1680
In front of discharge from oil/water separator	II-6	2	40	<10	1.4	--
15 m down gradient of discharge from oil/water separator	II-6	2	50	<10	17.8	--
Automobile salvage yard	II-4	11	<10	120	0.8	--
Control-outwash sand	--	--	30	50	0.8	280

c. Interpret existing data, most importantly, an assessment of base flow (the groundwater component) and surface water quality for all seasons is needed. If data are lacking, use inexpensive field monitoring devices (i.e., shallow, hand driven wells, spring samples, selected domestic wells, etc.) or collect base flow samples from several sites in the watershed.

d. Identify the locations of land use activities which can have an effect on surface water through groundwater flow.

e. Develop a broad network of groundwater monitoring well sites based on major land use activity regions, proximity to other monitoring stations, changes in nearby river morphology and proximity to areas where degraded water quality is noted.

f. Develop overlay map techniques or other data management tools. Information should be accumulated on the specific geologic setting and operational history at the different use areas.

g. Develop and apply a ranking system to determine which use areas and categories pose the greatest relative potential for contaminant input.

h. As needed, extend in-field monitoring to critical river reaches or higher potential contaminant areas. Include data monitoring for lower potential contaminant areas to serve as control sites and to test the validity of the ranking approach.

i. After final evaluations are made, continue long term monitoring of an abbreviated, optimized well network.

Additional suggestions concerning extrapolation to other watersheds are given by Anderson (2).

II-4. METHODS AND PROCEDURES

Basic data were obtained from the Southeastern Wisconsin Regional Planning Commission (SEWRPC), the Wisconsin Department of Natural Resources (WDNR), the U.S. Geological Survey (USGS), the Wisconsin Public Services Commission (WPSC), the U.S. Soil Conservation Service (SCS), private trade associations, municipal governments and a variety of other sources. As shown in later sections, overlay map techniques were employed as an interpretive tool in many cases. This approach has been accepted by many workers in the regional planning and natural resources management fields. It is more fully discussed by McHarg (3). The SEWRPC's Land Data Management System proved invaluable for data handling and display purposes. Aside from the system's ability to reproduce accurate land use information, the computer program storing detailed soils data was modified by request to SEWRPC. This resulted in several useful maps:

a. A characterization of the soils by their underlying geological (surficial) materials. The map was helpful in showing the areal geology around specific disposal sites, storage areas, pipe lines and sewer lines. A discussion of the methodology and limitations of the approach is included in Appendix II-A. The map was unsuitable to the reproduction methods used in this report. The original is available by contacting the Project Leader. The soils grouped within each surficial materials category are also listed in Appendices II-A-1 and II-A-2.

b. Maps characterizing the soils based on the properties of permeability and depth to the water table. Separate sheets were prepared for B and C horizons. The C horizon maps were used more frequently, especially in those cases where overlying soil horizons are likely not important (as in septic tank drain fields) or have probably been disturbed (as in some residential developments). The maps were used in several evaluations of areal use impact. For dealing with site specific uses, such as barnyard investigations, some modification is needed. Better results were sought in this case, by studying the somewhat more accurate, SCS county soils maps (4,5,6). The computer interpreted maps, based on dominant soil type (and hence, physical characteristics) in each hectare are believed to be of more than acceptable accuracy for the other interpretations. Soil groupings for each permeability/ water table class are listed in Appendix II-B.

A method aimed at assessing available contaminants in soils beneath selected land use sites was tested. McWhorter et al. (7) found that by saturating a small amount of mine spoils with an equivalent weight of water, an extract was obtained whose quality was very similar to the groundwater found underneath the sampled spoil pile. For the Menomonee project, a series of cores was taken from the upper foot of soil. The soil was slowly dried.

That portion which passed through a No. 10 (medium sand) sieve was saved. A representative 25 g sample was placed with 250 ml of deionized water in a comparatively inert plastic bottle for 16 hr. The amounts used should yield roughly a 10 to 1 dilution as compared to cited procedures. The mixture was shaken several times during the test period. Table II-2 displays the results of chemical analyses of the filtered extract, corrected for the dilution factor. Research should continue on the merits of such rudimentary though potentially useful laboratory tests.

Final evaluations as presented on the maps fall into two major categories: consideration of the overall input from an areally distributed land use (i.e., concentrations of septic tanks or croplands) or from distinct use sites (i.e., salt storage or solid waste disposal areas). In the former case, ranking the potential for contaminants to be released from an area, through soils interpretations, appeared to be the most logical approach in preliminary evaluation. Owing to the current lack of information on groundwater flow in the separate subwatersheds, it was not possible to go beyond this first step. Assessing the contaminant potential from site specific uses, necessitates comparing the relative probabilities for pollutants to be released from those areas and transmitted to surface waters. This involved an interpretive evaluation of the operational history of the site, its position within the geologic framework and in-field, reconnaissance analysis.

It is important to remember that the evaluations do not represent detailed collection and analysis of groundwater quality information at the specific sites or within the distributed use areas. Such an approach was impossible to initiate given the constraints imposed on this phase of the project. The maps do, however, serve as useful aids in evaluating observed surface and groundwater quality trends in the basin. Of equal importance, they identify those areas where future monitoring would be most critical. Except where specifically noted, the maps represent an accurate reduction of draft plates, drawn at a scale of 1:48,000.

II-5. RESULTS AND DISCUSSION

Solid Waste Disposal Areas

The impact of solid waste disposal practices on groundwater quality has received considerable attention in the last 10 years. These facilities represent--in some cases--a hazard to drinking water supplies or receiving surface water bodies. The locations of the 41 waste disposal sites in the Menomonee River Watershed are shown in Figs. II-1 and II-2. These represent sites which have been used by the private and public sectors within the last 25 years and which were identified in the files of the WDNR and by interviews with municipal officials and area residents. While the number may seem large, it is likely that there have been others. All sites were visited on a reconnaissance basis. This information was combined with interpretations on the surrounding geology and hydrology to develop the final maps. Specific comments on many of the sites are included in Appendix II-C.

Though eight sites have been given the highest rating, this only reveals an assessment of "slight to moderate" relative significance. No sites were deemed to represent an obvious, serious hazard to quality in the main river system. This does not imply that they are not important in a more local water quality scheme. As for the four currently operating sites of the highest rating, two are being monitored through the efforts of WDNR (sites 5 and 6). The other two are restricted to waste products which do not contain refuse, garbage or hazardous wastes. A fifth site, number 9, has caused some local surface water problems though remedial measures are being implemented. Of the three remaining "slight to moderate" all but one have been closed for over 10 years. As reported in Ruedisili (8), the Wisconsin Department of Health and Social Services suspected that site number 19 may have been a prime cause for contamination of neighboring domestic wells in the 1950's. Additional monitoring of these three sites might be advisable.

Monitoring wells installed for the study are not in locations which appear to be affected by the disposal sites noted on the maps. Well site 7 shows unusually high sulfates, a pollutant frequently associated with waste disposal. Although well site 2 appears to be located hydrologically upgradient from disposal site 25, groundwater "mounding" within the fill may have caused a reversal of groundwater gradients, or the waste deposits may extend beyond mapped boundaries.

Current waste disposal trends in the region appear encouraging from a water quality standpoint. Specifically, these trends are:

a. The movement towards concentrating waste disposal in sites with natural or artificial, low permeable liners combined with systems of leachate collection and outside treatment.

b. The emphasis on incorporating resources recovery schemes, thereby reducing waste quantities.

c. The strong environmental protection programs directed from Federal and State governments.

Barring unforeseen development, it is probable that solid waste disposal will present a decreasing future hazard to surface water quality in the basin.

Salt Storage

All known municipal and two major private road salt storage areas were examined. Field visits were conducted in the summer of 1977 and survey data collected by SEWRPC were studied. The salt represents a concentrated, highly soluble source for dissolved ion pickup in percolating rainwaters. Chloride is the main pollutant of concern. Some smaller quantities of toxic pollutants, such as ferrocyanate anti-caking compounds may also be present. For economic reasons municipalities outside urban areas use salt and sand mixtures rather than pure salt. Urban communities are concerned that sand will clog sewer lines. When considering storage sites as pollutant inputs to groundwater, the area exposed to rainfall either directly in the storage pile or indirectly, if washed off and held in the soil profile, is an important control on total quantities of contaminated percolate. A highly concentrated, steep mound of salt exposes less surface area than a pile which has been eroded to yield a significantly higher effective salt recharge area. Results of extraction analyses of soils at two salt storage sites in the watershed are shown in Table II-1. The potential for recharging high concentrations of chloride is apparent.

In salt storage areas, operating procedures are critical to overall environmental impact. At some sites large quantities of salt were kept in the open, without cover, upon broken asphalt or permeable soil surfaces. More satisfactory protection was noted at other sites, some showing excellent, semi-closed sheds, up to one completely closed and specially designed "beehive" shelter. Comments on individual facilities are included in Appendix II-C-2. The rating put equal weight on operational procedures as well as site setting.

Those sites with the highest relative potential (Figs. II-3 and II-4) are located along the lowermost reaches of the Menomonee River, just west of the estuary. It is uncertain whether the river is gaining groundwater from the immediate surroundings or whether groundwater from beneath the sites discharges farther east and into the estuary. The sites represent potentially significiant non-point sources of contaminants if not properly managed.

Metal Storage

Automobile salvage yards and metal scrap yards often constitute significant visual pollution. The surface runoff from the sites, frequently high in dissolved salts, metals, suspended sediments, oils and grease, is another obvious problem. Whether dissolved contaminants transported to the groundwater system constitute a similar hazard is uncertain. The relative potential impact from these sites in the Watershed was evaluated on a preliminary basis, as shown in Figs. II-3 and II-4. The analysis relied on similar criteria to those used in evaluating salt storage areas. Any approach at field reconnaissance, beyond the most superficial, was met with disfavor by many yard managers.

There are two significiant concentrations of metal storage areas in the Watershed. The first, near the junction of the Menomonee and Little Menomonee Rivers, is believed to be underlain by a poorly permeable clay-rich layer in the unconsolidated sediments. Segments of the surface waters in this region are not supported by groundwater discharge. These factors would tend to lessen overall impact. The second group of sites is in the lowermost reaches of the watershed and contains the largest facilities. Again, it is uncertain where groundwater from this area discharges. These two storage site concentrations are areas where continued study may be warranted. Extraction analyses at one salvage yard in the Watershed showed the potential for some increase in sulfate concentrations in percolating rainwater (Table II-1).

Liquid Waste Management

Three sources of liquid waste were identified as potential contributors to groundwater contamination. They are: a. sewer line leakage; b. industrial waste water; c. sewage sludge.

Infiltration of groundwater into sewer pipes is well known to sanitary engineers. Infiltration of groundwater may occur through weak zones at pipe joints or breaks or when pressures within the pipe are lower than the surrounding groundwater pressures. Auld (9) cited average values of infiltration of 18,700 L/day/ha of tributary Watershed or 70,500 L/day/km of major trunk sewer. Though this represents a large amount of extra fluid which must be handled by the sewage treatment plant, similar quantities of liquid waste can exfiltrate from the pipe any time fluid pressures within the pipe are greater than those in the surrounding medium. This most easily occurs when the pipe is placed above the water table. The ability of the contaminants--principally nutrients, chlorides and microorganisms--to flow with the groundwater to surface waters is largely a function of surrounding geology.

Figs. II-5 and II-6 show the relative potential for groundwater contamination of major trunk sewers in the Basin. The rating considered the thickness and texture of the unconsolidated host sediments, the distance from the pipes to the surface water and the overall direction of groundwater movement. Three separate categories were designated as follows:

a. Sections most likely to affect surface waters if leakage occurs. These include sewers which are bedded in relatively permeable deposits, upgradient and near to receiving surface waters. Information on actual depths to the water table would provide additional help in evaluating the potential for groundwater contamination.

b. Sections in which surface waters are recharging the groundwater system. In these settings, the water table is usually deeper than in Category a. Leakage from sewer lines is then quite possible. Though the contaminated groundwater would not discharge in the immediate vicinity, it might flow to a gaining stream segment downgradient.

c. Sections less likely to affect surface waters by groundwater flow paths.

The ranking system appears to be a viable approach for the Menomonee River Watershed and is supported by field groundwater quality data. Data from two well sites show elevated levels of fecal coliform indicator organisms (1). The sites are close to sewer lines and overflow devices. Based on the independent analysis outlined above, both locations were noted to be susceptible to sewer line impacts. Many more smaller sewer lines are present in the basin and may be sources of pollutants. Separate storm sewers are frequently installed with less than adequate sealing. They are as yet an unevaluated problem.

Though the Menomonee River Watershed is highly industrialized, only two facilities are reported to use wastewater disposal systems which discharge to groundwaters. This is a much smaller number than originally expected and is probably a result of:

a. The industrial wastes generated in the area are less amenable to such treatment;

b. The lack of soils well suited to on-site process water disposal (10); and

c. The presence of a dense network of municipal sewer lines and of many surface water segments, both of which could receive such effluents.

Information on these two sites contained in the files of the Industrial Wastewater section of the WDNR was obtained and both sites were visited in the field. It is likely that the effluents have a minor effect on surface waters. The first site, noted in Fig. II-5, is a concrete block manufacturing plant. It yields an average flow of 75,900 L/day to a long dry ditch infiltration area. The WDNR believes the quality of the effluent to be generally good. The second site, noted in Fig. II-6, is an oil storage and distribution area. The surface runoff from loading and unloading is directed to an oil-water separator. The clarified liquid is discharged into a diked area surrounding the oil storage tanks. The average daily flow is listed in their State permit application as less than 3,790 L/day. Wastewater quantities and qualities are not deemed to be hazardous by the WDNR. The soil extraction analyses presented in Table II-1 lend some additional support to this belief.

Creosote contamination of the Little Menomonee River south of Brown Deer Road has been reported (11). The waste is believed to have originated from a surface water discharge. Test borings on the property of the suspected discharger have revealed some creosote in underlying soils. While the density and relative insolubility of creosote would tend to discourage movement through groundwater, the importance of this mechanism has not been defined completely at the subject site.

In some areas of the country, aquifers are used to supply cooling water for air conditioning systems and to receive heated water in return. It was expected that some industries in the area would be using this method. Non-contact cooling water is not regulated by the WDNR. Based on a telephone survey of air conditioning contractors and engineering consultants, it does not appear that this method is practiced in the Watershed. Some factors which control this situation include:

a. Wisconsin's general prohibition of "injection wells" regardless of the character of the water used for recharge;

b. The belief among industry that private wells represent a less reliable source of supply (because of generally falling groundwater levels) than municipal sources; and

c. The generally successful use of continuous pumping recirculation systems (closed loop) in most plants.

Based on this analysis, non-contact cooling water disposal is not perceived as a current impact on groundwater in the basin. It is possible that with the increasing recognition of groundwater reservoirs as possible temperature storage units, more attention will have to be devoted to such resource quality protection in the future.

The four municipal sewage sludge disposal sites in current use in the Basin, are shown in Fig. II-5. The waste is normally mixed into the uppermost soil layers during the spring and fall. While these seasons do represent significant recharge periods to groundwater, the sites are not likely to constitute an important impact on the river system. The sites are closely monitored by WDNR. Application rates and techniques follow best management practice guidelines developed through the University of Wisconsin-Extension and by several State agencies (12).

Runoff from Roads

Surface runoff from highways and residential streets has been shown to contain high levels of dissolved and suspended contaminants of variable composition (13;14). Excessive concentrations of dissolved chloride are considered to be the most significant contributor to groundwater contamination. Field data collected during the IJC project suggest that this is the most significant modification of groundwater quality attributable to urbanization. Assessing its full magnitude would involve an additional, major research effort. Figs. II-7 and II-8 were prepared as preliminary aids for grappling with this problem. The maps display the textures of soils bordering major U.S. and county highways in the watershed. Decreases in soil permeability, fostering lower fluid recharge rates, also foster lower chloride transmission. The majority of roads categorized are bounded by soils of moderate permeability; therefore of moderate hazard. This analysis is, of course, preliminary in nature and does not consider the location and discharge point of storm sewers. The maps are a first approach at studying this problem. As for comparison to field data, well site 5 had the highest levels of chloride found in the unconsolidated materials (1). The site adjoins roads which, based on these maps, appear to be bounded by the most permeable soils. The soils in the metropolitan Milwaukee area have not been mapped by SCS, so the roads could not be rated in that area.

Oil and Gas Facilities

Leaking oil and natural gas pipelines in some settings, can contribute dissolved hydrocarbons to surrounding groundwaters. Advances in cathodic protection of pipelines has cut dramatically the instances of leakage through rusted, weakened zones. Periodic flow monitoring devices are also used to check for breaks along the lines. According to engineers at Wisconsin's Public Services Commission (personal communication, 1977), no instances of groundwater contamination from pipelines have been reported during the last few years. If leakage does occur, large quantities of contaminants could conceivably be transmitted to groundwaters before corrective actions are implemented. With this possibility in mind, Fig. II-9 was prepared. Major oil and natural gas pipelines are shown in their approximate locations. The orientation and position of these lines were taken from regional maps and should be considered only approximate. Those sections which appear to pass through permeable deposits closest to the river, are denoted as having a higher potential for contamination if leakage occurs. Only major gas lines are shown; many kilometers of smaller lines which branch off the major lines are not shown.

Three principal oil storage facilities in the basin have been identified and are shown on Fig. II-9. The largest by far, is the most northerly concentration of tanks. Again, no history of groundwater contamination has been reported. What remains as a more critical potential problem are the large numbers of fuel storage tanks at unknown locations in industrial facilities and gas stations. Regulatory control of these units is sketchy at best. Many factories have tanks with capacities of thousands of m^3. Gas stations typically retain about 100 m^3 in storage. Their overall impact on local water quality is an important, yet unassessed factor in urban watersheds.

Septic Tanks

Maps showing land use and population density (11) were overlain with maps showing sewer service areas to determine major concentrations of septic tank use. No appreciable regions of medium density (18.2 to 57 persons/net residential hectare) or high density (> 57 persons) concentrations of development were found which used septic tanks. Significant groupings of low density residential (1.2 to 18 persons) areas are shown in Figs. II-10 and II-11. Small, more isolated housing tracts would not be identified on the general land use map upon which the analyses were made. Considering an average daily discharge of 375 L/day/person (15), this represents a small amount per hectare, but a more considerable amount in concentrations of use areas. Total discharge to groundwater can easily average 510 $m^3/day/km^2$ in low density residential areas.

The method used to evaluate septic tank contamination potential has been modified from an approach presented by Miller (16). He found that areas of Delaware with more permeable soils and deeper water tables (> 1.5 m from the ground surface), corresponded to regions with elevated nitrate levels in groundwater. Similarly, regions with high water tables and more slowly permeable soils favored overland runoff of septic tank effluent and bacterial contamination of wells. By extending his findings, those more reducing environments would tend to prevent the oxidation of ammonia in the effluent to nitrate forms. From a groundwater standpoint, bacterial contamination represents a very local hazard, while ammonia concentrations can remain for longer subsurface flow paths. Unlike nitrate however, ammonia can be removed to some degree through adsorption during travel through the aquifer. Nitrification can occur with eventual discharge to surface waters.

Soils in the watershed were classified according to depth to water table and permeability characteristics (Appendix II-B). Examining the C horizon in this case is especially important since drain fields will most often be placed primarily above this soil horizon. The breakoff point for permeability classes are similar to those used by the SCS (17). They were modified slightly to incorporate field data gathered by University of Wisconsin-Extension (18). The actual acreage of the Watershed affected by this change is < 1%.

The dominant class in the basin is denoted as "moderate-ammonia." Few regions favoring the more serious "high-nitrate" forms were shown. Only one IJC well site is placed clearly downgradient from a concentration of septic tanks (shown largely as "moderate-ammonia"). The well shows the highest concentration of ammonia found in the unconsolidated aquifer (1). This value (mean = 0.86 mg/L) is still relatively low from the standpoint of an aquatic ecosystem hazard. While other factors may be involved (i.e., sewer line leakage), it does lend supportive evidence for continuing research on this problem. The prevalence of "moderate ammonia" ratings reflects the general high water table conditions and poor septic tank suitability setting for most residential areas in the Basin.

Current land use plans for the Menomonee River Basin (11) favor the extension of the metropolitan Milwaukee sewage treatment system to a greatly increased service area. Fig. II-12 shows septic tank ratings determined for future planned low density residential areas, outside those expected to be sewered. Assuming the overall trend is eventually followed, the potential problem from septic tanks will decrease while that derived from sewer line leakage will become of greater concern.

Barnyards

There are over 40 barnyards in the Watershed. They mostly confine beef cattle and are small, usually holding 20 to 100 animals (11). Assessment of potential for groundwater contamination from barnyards (Fig. II-13) was based on soil interpretations similar to those performed for septic tanks. Because of the size of the yards, the more generalized computer maps used in septic tank studies were not sufficiently precise for this phase. The steps that were followed included:

a. Barnyard locations identified by SEWRPC on recent, detailed air photographs were consulted.

b. From the photographs, sites were accurately located on USGS topographic maps and SCS county soils maps (4;5;6).

c. The orientation of overland runoff from each yard was measured on the topographic maps.

d. The orientation was plotted on the soil sheets and 150 m typical flow path was drawn.

e. The soils beneath this flow path were classified according to permeability and depth to water table for B and C horizons.

f. A summary rating was determined based on dominant physical characteristics.

Most research on groundwater impacts from barnyards has been concerned with highly concentrated (several thousand animals) feedlot operations (19). Smaller yards in similar settings do pose smaller threats. Based on this preliminary assessment, only four barnyards in the Watershed appear to be located in largely permeable soils. Isolated barnyards are undoubtedly less significant on a regional scale than areal concentrations of barnyards, which occur, for example, in the headwaters of the Little Menomonee River. Whether nitrification of ammonia from feedlots is a factor in the elevated nitrate levels found in the upper Watershed is uncertain. According to the U.S. Agricultural Stabilization and Conservation Service in Washington County (Simpson, personal communication, 1977), daily removal and spreading of manure is practiced by many farmers in the area. The need for such cleanliness is especially important in dairy operations. These factors tend to reduce the overall impact from barnyards in the basin.

Cropland

Fertilizer and pesticide inputs to groundwater can have a deleterious regional effect on surface water quality (20). Agriculture in the Menomonee River Watershed is concentrated primarily in Washington and Ozaukee Counties. Field data on low surface water flows and some information on spring water quality, shows an increase in dissolved nutrients over background levels. Nitrates are conservative ions and may be transmitted readily in groundwater. While nitrate is usually below 0.5 mg/L of nitrogen in uncontaminated groundwater, analyses for the upper Watershed indicate that at times nitrates can be as high as 2 or 3 mg/L of nitrogen. While still below the drinking water standard of 10 mg/L of nitrogen, these levels can enhance the growth of nuisance organisms in some parts of the river system. Fig. II-14 ranks the relative potential for groundwater contamination from different cropland areas. Soils are ranked solely by permeability class, with higher values allowing greater influx of contaminants. Differentiating between inputs of nitrate or ammonia is not deemed possible based on available data. Crop type was not considered in this preliminary analysis but should be included in any later work. Heavily fertilized corn or hay fields spread with manure would likely contribute higher loadings than nitrogen fixing, lower nitrate releasing soybean fields. Crop rotation from fertilized to non-fertilized conditions should also be considered in a detailed assessment. Areas of probable cropland for the year 2000 (11), are rated in Fig. II-15. Examining both maps, the more permeable fields near the little Menomonee River stand out. Future monitoring should be directed to at least these areas.

Residential Lawns

Figs. II-16 and II-17 rank soils for those areas noted in current residential use, as to their potential for contaminant transport. The rating follows the breakdown developed for croplands. A major part of Milwaukee County could not be evaluated due to a lack of soils information. In the computer printout upon which the maps were based, those areas devoted to impervious surfaces such as structures and pavements could not be differentiated from those areas covered by lawns. The amount of contaminants transmitted to groundwater from lawns that have received fertilizers, pesticides and supplemental watering has attracted little attention in the literature. Although each lawn undoubtedly has little impact, because substantial portions of the watershed are involved in such use, some concern should be raised. Though field evidence from this study (1) indicates that nutrient loadings to groundwater were low in suburban areas, the fate of contaminants from lawns to eventual surface water discharge is poorly understood. The ratings (Figs. II-15 and II-16) developed in this phase of the project should help in designing a useful future study.

Fallout of Air Pollutants

Data on the quality of rainwater and air pollutant fallout were collected and analyzed as part of the IJC study on the Menomonee River Watershed. Analyses of inputs to four monitoring stations in the Milwaukee area were conducted from August, 1975 through December, 1976 (Emmling, University of Wisconsin-Madison, Water Resources Center, personal communication, 1977). The major contaminants of interest relevant to groundwater quality are chloride and sulfate. Chloride values during periods when road salting did not occur were at a maximum of several tenths of a mg/L of rainwater. During salting periods, values increased to 7 or 8 mg/L, still an insignificant concentration as compared to surface runoff. Sulfates were deemed to be good indicators of urbanization. Values in more rural settings were typically between 2 and 4 mg/L. Urban areas were higher, but still largely under 10 mg/L. One station was placed immediately downwind of two large pollutant sources, a foundry and a coke plant. Maximum values were still under 15 mg/L. Unless some unusual concentration mechanism is effective once infiltration occurs, significant groundwater contamination from air pollutant fallout is unlikely.

Other Land Uses

The land uses examined in this study do not represent all possible sources of contaminants. Those studied are believed to be the most significant at this time. The presence of other chemical or industrial storage practices which could impact groundwater is certainly possible. One likely contaminant source involves the three railroad storage yards in the watershed. These yards frequently contain liquid waste or petroleum product spills. Filling of low, wet areas with demolition or other solid waste has been reported from other regions. These yards should also be included in future groundwater analysis.

The problem of hazardous waste disposal is being addressed by government regulatory agencies. Presently there are no legal receivers of these waste products in the Menomonee River Watershed. However, because increased future reliance on land disposal of sludges and chemical wastes is likely, this contaminant source must be addressed in future work on surface and groundwater quality relationships in the Menomonee River Watershed.

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APPENDIX II-A. PREPARATION OF SURFICIAL MATERIALS MAP

The surficial materials map was used routinely in the identification of geologic settings around potential sources of groundwater pollutants and in the interpretation of local and regional groundwater flow systems. The Land Data Management System of SEWRPC was used to prepare the surficial materials map. The System has the capability of printing computer maps displaying soils information for several size areal units. Soil data, catalogued by SCS field number, for each "cell" (1 hectare) can be quickly displayed on either of two scales (1:24,000; 1:48,000).

Soil descriptions were examined (21), for each of the approximately two hundred soil types in the Basin. The soils were first catalogued into six materials categories based on descriptions of the substratum for each soil. The units were: till, glacial fluvial sediments, alluvium, thick organic deposits, glacial lake sediments and thin unconsolidated cover over bedrock. Descriptions of each type are given in Table II-A-1. While most soil types could easily be categorized, there were several cases which warranted reference to additional soil survey information.

After preliminary designations, an attempt was made to divide the till bodies into the two major types present in the Basin. Till believed to correlate stratigraphically with the Haegar Till is generally sandy and buff colored. The grey, silt and clay rich till is probably correlative with the Wadsworth Till. The distinctive difference in texture of the tills in an important control on groundwater conditions and pollutant movement.

Laboratory tests of the lowermost ("C") soil horizon in each till soil type was examined, using data available from SEWRPC (21). These were used as the basis for the breakdown if it was apparent that the C horizon samples were also representative of the substratum. Where these two did not match, the decision was made from published field descriptions of substratum texture and color.

Several soils were categorized by one dominant type overlain by up to 0.6 m of distinctively different material. This condition usually involved thin organic rich layers over till or thin sand and gravel layers over lake beds. In these cases, the lower unit was used in classification.

Table II-A-2 shows the final breakdown of soil numbers by material type. Five additional, non-geologic units were added to the seven previously discussed groups. This list was forwarded to SEWRPC for final map printing.

A simple check was conducted to verify the accuracy of the computer system for cataloging and printing soils data. Twenty five points were chosen at random on the computer maps. The dominant soil listed for each of those cells was noted. The original soil survey sheets were consulted and interpretations made on surficial materials and permeability--water table class for both soil horizons (see Appendix II-B). Only one of the 25 points did not agree. The one error was deemed unimportant since the interpretation of dominant soil type was difficult for the chosen cell.

Limitations of surficial materials maps

While the methodology for producing surficial materials computer maps results in a useful product, there are several limitations which are inherent in the method, including:

a. Overall accuracy. The map information shown does not represent actual in-field identification. It is instead, office interpretation of soils information collected for purposes other than classification by surficial materials. This discrepancy represents the first, basic source of error.

The accuracy of surficial materials maps has been investigated recently by McCartney (22). Statistical tests comparing actual field checks with generalized surficial materials maps (Wisconsin Geological and Natural History Survey) for a portion of Dane County pointed to an overall minimum accuracy of approximately 63 to 72%.

b. The lack of landform information frequently available on surficial geology maps. The latter normally show such significant bodies as end moraines, ice contact deposits, etc. These geologic features serve as important controls over surface and groundwater flow systems.

c. The two dimensional nature of the maps. Since the original soil data are almost always based on shallow subsurface exploration, variability in the third dimension cannot be assessed. This of course, is an inherent problem with most other types of geologically-related maps. Fortunately many water well logs are available in the Basin. These can be compared with surface information to determine stratigraphic relations with depth in the unconsolidated sediments.

d. Boundary errors. Since the data are presented on the basis of dominant material in each cell, material boundaries will always be shown at the contact between cells rather than within them. This often conflicts with actual field conditions, where boundaries can occur at any location. Since the cells are physically small units in the final map and materials boundaries are most often diffuse in nature, this limitation is not believed to be critical to the aims of the groundwater study.

e. Integrating nature of the cell method. As the procedure prints the dominant material type in each cell rather than all types, some smaller units may be missed and others overemphasized. Again, the small size of the cell and the overall aims of this project allow acceptance of the method within these confines.

Table II-A-1. Composition of surficial materials in the Menomonee River Basin.

Glacial Till

Till is dominantly an unsorted, unstratified sediment deposited directly from glacial ice without significant modification by fluvial activity. The generally silty to clayey tills in the Basin are believed to correlate with the Wadsworth Till, identified in other portions of the Great Lakes Region. The largely sand rich tills in the Basin are believed to correlate with the Haegar Till.

Glacial Fluvial Sediments

Deposits principally of sands and gravels, they were formed either against glacial ice (ice contact) or from meltwater sedimentation beyond active ice bodies (outwash). Small bodies of till or glacial lake sediments are frequently incorporated in them but may be too small to map.

Thick Organic Deposits

These result from sedimentation of organic rich deposits in modern marshes and swamps.

Glacial Lake Sediments

Formed in temporary glacial lakes, they are composed largely of fine sands, silts and clays and are frequently stratified (varved).

Alluvium

The deposits of the modern stream and floodplain system, consisting primarily of sands and gravels with lesser amounts of silt and clay.

OTHER FEATURES

Thin Unconsolidated Cover Over Bedrock - bedrock encountered within 1.5 m of the ground surface.

Open Water - lakes and ponds.

Made Land - cut and fill areas from human activities.

Gravel Pits and Quarries

Dumps

Unknown - largely, areas unmapped during original soil survey work.

Table II-A-2. Soils-surficial materials classification

Units	Soil numbers*												
No. 3	63	82	113	160	161	178	212	213	215	231	243	260	
Sandy till	278	343	344	345	355	357	360	360X	361	362	362X	363	
	364	365	366	394	397X	454	455	455V					
No. 4	297	298	299	300	325	338	397	397Y	398	399			
Clayey till													
No. 7	40X	42X	70	72	73	73V	75	76		76V	76Y	76Z	
Glacial fluvial	78	80	84	86	87	106	109	119	123	126	126Y	126Z	
sediments	172	173	173Y	174	176	181	182	182V	182Z	203	203Y	212X	
	233	233V	233Y	233Z	282	288	324	326	332	335	387	391	392
No. 11	7	11	11W	23	238	328							
Alluvium													
No. 12	4	327	450	451	452	458	460	461					
Thick organic deposits													
No. 14	18	21	24	26	27	28	29	36	38	40	40Y	42	
Glacial lake	42Y	47	48	51	53	173V	213V	217	218	218Y	251	263	
sediment	266	268	272	340	369	456	457						
No. 15	38R	43	76R	125	161R	204	206	208	212R	213R	262A	266R	
Thin drift over bedrock													

	Other categories "soil numbers"		
No. 20	Lake pond water		
Water			
No. 30	MLC	MLY	MLZ
"Manmade land"			
No. 40	GP	Quarr	Quarr
Gravel pits and quarries			
No. 50	Dump		
Waste disposal sites			
No. 60	Unknown		
Unknown			

---

*Soil number from SEWRPC Planning Report No. 8

APPENDIX II-B. SOIL-PERMEABILITY-WATER TABLE GROUPINGS

Table II-B-1. Soil-permeability-water table groupings

Group	Soil numbers*											
B Horizon												
Rapid; high	251	262R	387									
Rapid; low	75	288	355									
Moderate; high	7	7W	11	11W	21	23	24	26	27	28	29	36
	38	38R	42X	42Y	47	48	51	53	63	76	76R	76V
	76Y	76Z	78	80	82	86	87	109	113	123	126	126Y
	126Z	174	176	178	181	182	182V	182Z	203	203Y	212	212R
	212X	213	213R	213V	215	218Y	231	233	233V	233Y	233Z	238
	243	263	278	297	299	300	303	306	324	325	326	328
	332	335	340	344	345	363	363R	364	369	397	397Y	399
Moderate; low	18	40X	40Y	43	70	72	73	73V	84	106	119	125
	160	161	161R	172	173	173V	173Y	204	206	208	260	266
	266R	268	282	304	308	343	357	360	360R	360X	361	362
	262R	362X	365	366	391	392	394	397X				
Slow; high	4	40	42	217	218	298	327	338	398	450	451	452
	454	455	455V	456	457	458	460	461				
C Horizons												
Rapid; high	42X	76	78	80	86	87	109	123	126	174	176	181
	182	203	212X	233	251	324	326	332	335	345	387	452
	454	455	455V									
Rapid; low	39R**	40X	43	70		72	73	75	76R**	84	106	119
	125	161R	172	173	204	206	208	212R**	213R**	262R**	266R	282
	288	303**	304	306**	308	355	360R	360X	362R	362X	363R**	391
	392	397X										
Moderate; high	7	7W	11	11W	23	26	27	28	29	36	38	42Y
	47	48	63	76V	76Y	82	113	126Y	178	182V	203Y	212
	213	213V	215	218Y	231	233V	233Y	238	243	263	278	297
	299	325	328	344	363	364	397	397Y	399			
Moderate; low	18	40Y	73V	160	161	173V	173Y	260	266	268	343	357
	360	361	362	365	366	394						
Slow; high	21	24	40	42	51	93	76Z	126Z	182Z	217	218	233Z
	298	300	327	338	340	369	398	450	451	456	457	458
	460	461										

Note: "High" water table -- within 1.5 m of the ground surface during a significant portion of the year.
"Low" water table -- > 1.5 m from the ground surface during a significant portion of the year.
Rapid permeability -- > 1 cm/hr.
Moderate permeability -- between 0.1 to 1 cm/hr.
Low permeability -- < 0.1 cm/hr.

---

*Soil numbers from SEWRPC Report No. 8.

**May be more appropriately placed in the "Rapid; high" group.

APPENDIX II-C. COMMENTS ON SELECTED LAND USE ACTIVITIES

Table II-C-1. Comments on solid waste disposal areas shown in Figs. II-1 and II-2

Category: Mixed Refuse - Active

Map No. 1 - small, well operated site
- outside the surface watershed

5 - principal waste disposal site for the region
- substantial water quality monitoring data available
- some impact to local surface waters
- leachate collection system currently being expanded
- licensed receiver of industrial wastes

21 - outside the surface watershed
- waste disposal near the water table
- movement of pollutants in deeper flow paths towards the Menomonee River is possible
- leachate collection system to be implemented in the future

Category: Mixed Refuse - Closed since 1967 (approximate date)

9 - considerable ponding of leachate from groundwater discharge
- leachate spills have caused local surface water problems
- remedial measures under implementation

14 - closure has been inadequate; state of enforcement orders are pending

16 - closure has been inadequate

17 - mixed wastes from a brewing company
- a filled wetland
- closed fairly well
- final rating represents a collective appraisal of sites 13, 14, 16 and 17

32 - filled gravel pit; waste deposits within groundwaters
- well graded and fairly adequate cover soil; currently in parkland

34 - site of current waste transfer station

Category: Mixed Refuse - Closed before 1967 (approximate date)

19 - well graded and covered
- currently in use as portion of golf course (not irrigated)
- waste had been deposited in old quarry immediately abutting river

26 - very deep fill bordering the main channel of the river
- leachate springs noted at the base
- may be converted to city park in the future

29 - old fill in deep quarry
- covered with asphalt and concrete, used for parking area for county stadium

38 - very large, shallow fill in old wetland
- currently supports storage tanks and a waste transfer station

Category: Demolition; Wood - Active

15 - due for closure next year

20 - accepts only noncombustible waste
- below the water table; seepage from rock walls collected and removed

22 - well operated fill in old gravel pit
- some small leachate flowage to Underwood Creek

34 - portion of site used for waste transfer area

Category: Demolition; Wood - Closed

Map No. 3 - tires and brush in an abandoned quarry

8 - brush and diseased trees mostly burned

11 - waste derived mostly from construction of I-94
- covered and used for an industrial park

12 - principally used for brush burning

18 - small contractors site for brush

24 - closed well
- some small leachate flowage

25 - concrete and demolition fill in quarry
- food store and parking lot now on surface

Category: Other Materials - Active

7 - manure from packing plants
- some local, documented surface and groundwater contamination problems

23 - manure and hay bedding from municipal zoo
- surface runoff to storm sewer

27 - foundry sand and scrubber sludge
- very deep waste fill abuts main channel of the river

33 - foundry sand

39 - foundry sand, fly ash and slag
- outside the surface watershed

Category: Other Materials - Closed

2 - small fly ash disposal site from coal fired power plant

10 - metal sludges
- inadequately closed
- surface drainage feeds an intermittent stream

28 - small fly ash disposal site

30 - cyanide waste disposal pits
- potential pollution problem had been previously examined
- contaminated soil believed to have been excavated and removed within last 5 years

35 - foundry sand, demolition and wood waste

37 - industrial ash
- now owned by Milwaukee County, possibly for freeway extension site

Table II-C-2. Comments on road salt storage sites shown in Figs. II-3 and II-4

Map letter	Winter storage (tonne)	Comments
A	180	- completely enclosed shed on pad; both in good condition - would serve as good control in any future monitoring work
B	135	- three walled shed - broken pavement and unlined drainage way can allow infiltration
C	18 to 27	- outside pile on broken pavement - runoff through discontinuous ditches and storm sewers
D	1,800	- completely enclosed "beehive" shelter
E	20	- inside garage - runoff across parking lot in good condition; to storm sewer
F	680	- inside garage - runoff across short concrete surface to storm drain
G	545	- mostly inside garage; some outside pile
H	270	- salt pile on concrete pad - runoff across unlined ditch
I	1,100 to 1,350	- two sheds on cracked pavement
J	680	- inside three-walled shed with tarpaulin across open front - short runoff path across well maintained pavement
K	54,500	- open piles at time of field visit; operator reports tarpaulin used during maximum storage period - immediately adjacent to main channel of the river
L	135	- kept in bags; inside garage
M	34,500	- open piles on crushed rock pad at time of field visit; operator reports tarpaulin used during maximum storage period - immediately adjacent to main channel of the river
N	680	- three-walled shed - short runoff path across well maintained pavement
O	45	- inside garage
P	450	- inside garage; some piles outside during winter
Q	90	- open piles on asphalt - highly broken pavement - storage site to be moved soon

PART III

MODELING AND EXTRAPOLATION TO OTHER WATERSHEDS

by

M. P. ANDERSON

ABSTRACT

A groundwater quality model was identified to aid in the task of extrapolating the findings of the IJC-Menomonee River Pilot Watershed Study to other watersheds in the Great Lakes Basin. The model was applied to the Menomonee River Watershed and calibrated using field data reported by Eisen and Anderson (1). For modeling purposes the Watershed was divided into eight areas with similar land use and hydrogeology. Because chlorides from road salt runoff was determined to be the major contaminant transported to the river in groundwater, the response of the aquifer to application of road salt was simulated in each of the modeling areas.

In 1977-78, the light urban area on the west side of the river between Butler and 70th St. contributed the most chlorides to the river. This area also had the highest groundwater discharge rate although chloride concentrations in groundwater were not especially high. The results of the model suggest that in most areas of the Watershed, average chloride concentrations will increase for several years if application of road salt remains at least as high as during 1968, the year for which chloride loading rates were estimated for use in the model. In the future, loading rates from suburban areas could surpass the loading rate for light urban land use. Because of the high percentage of paved surfaces in the heavy urban areas in the lower watershed and the resulting low groundwater recharge rates, groundwater loading rates from these areas were relatively low.

In other watersheds, the nature and amount of contaminants transported to the river in groundwater will depend upon the types and distribution of land use and the hydrogeology, especially the groundwater recharge rate. However, in most developing watersheds, it is expected that chlorides from road salt runoff will be a major source of contamination. In addition to groundwater discharging to streams entering the Great Lakes, direct discharge of groundwater to the Lakes should be considered. In a recent study, Cartwright et al. (2) demonstrated that groundwater discharge in the nearshore area of southwestern Lake Michigan may be significant in terms of quantity and quality. The model tested during the present study can be used as a tool in estimating the average concentration of a contaminant in groundwater discharging to a stream. Groundwater loading rates may be calculated and probable changes in groundwater quality caused by changes in land use can be predicted.

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III-1. INTRODUCTION

Groundwater-surface water interactions in the Menomonee River Watershed were examined and potential sources of contamination which could contribute pollutant loads to the Menomonee River System through groundwater discharge were identified (1;3). The third goal of the IJC project was to develop the predictive capability necessary to facilitate extension of the findings from the Menomonee River Watershed study to other urban settings. The purpose of the third phase of the groundwater subproject was to identify and test a model to aid in the extrapolation process.

III-2. CONCLUSIONS

a. The Gelhar-Wilson groundwater quality model can be used in extrapolating the results of the IJC-Menomonee River Pilot Watershed study to other watersheds in the Great Lakes Basin.

b. The nature and degree of groundwater contamination can be expected to vary depending on the distribution of land use and the hydrogeology of the watershed. However, in urbanizing watersheds similar to the Menomonee River Watershed, chlorides from road salt runoff are likely to be a major source of groundwater contamination.

c. In the Menomonee River Watershed data from the model suggest that in most areas of the watershed, average chloride concentrations in groundwater will increase for several years if application of road salt remains at least as high as during 1968.

d. The Gelhar-Wilson model can be used as a tool in estimating the average concentration of a contaminant in groundwater discharging to a stream. Groundwater loading rates may be calculated and probable changes in groundwater quality caused by changes in land use can be predicted.

III-3. RECOMMENDATIONS

Ideally, a record of several years documenting groundwater quality changes is needed to calibrate and establish confidence in the model. Gelhar and Wilson (4) demonstrated that the model simulated changes in chloride concentration for an area in Massachusetts where such a record was available. For the Menomonee River Watershed, it was assumed that the model would approximately predict the transient response of the system and the model was calibrated using only one average yearly concentration.

In areas for which no groundwater quality data are available, the model could be used to gain insight into the relative response of the system to changes in land use. However, the validity of the actual concentrations calculated by the model will depend upon the accuracy of the input parameters. It is recommended that where possible, an historical record be used to calibrate the model. When this is not possible, the model is best used to gain insight into the relative response of the system to land use changes or changes in management practices.

III-4. METHODS

Model Selection

Although it is desirable to represent the complex processes operative in groundwater systems as completely as is theoretically possible, it is often impractical to use complex models in managing a watershed. Typically, very little information is available on groundwater quality or quantity. Therefore, in general, detailed modeling is not possible. An ideal model would be one which generates results useful for regional planning yet requires few input data.

In this study, two models were tested--a distributed parameter model and a lumped parameter model. A distributed parameter model is one in which the variables are determined at several discrete points or nodes in the system, while in a lumped parameter model the groundwater system is treated as a point in space and only spatially averaged values of the variables are calculated. Because it was hoped that it would be possible to consider spatial variation in groundwater quality as well as temporal changes, the initial modeling attempt centered on development of a distributed parameter model. The scanty field data did not justify use of a two-dimensional model, therefore, a one-dimensional groundwater flow model was coupled to a one-dimensional contaminant transport model which included the effects of dispersion. The differential equations which represent groundwater flow and mass transport for this modeling scheme are:

$$\frac{\partial}{\partial x}(Kh\frac{\partial h}{\partial x}) = S\,\frac{\partial h}{\partial t} - W \qquad \text{Eq. (1)}$$

where

h head (length)
K hydraulic conductivity (length/time)
S storage coefficient
W recharge rate (length/time)
x space coordinate (length)
t time

and

$$\frac{\partial}{\partial x}(D\frac{\partial c}{\partial x}) - \frac{\partial (cq)}{\partial x} = nh\,\frac{\partial c}{\partial t} - c'W \qquad \text{Eq. (2)}$$

where

c	concentration (mass/length^3)
c'	concentration of source fluid (mass/length^3)
D	effective coefficient of dispersion for the entire thickness of the aquifer (length^3/time)
n	porosity

and

$$q \text{ is } - Kh \frac{\partial h}{\partial x}$$

Eqs. (1) and (2) were written in finite difference form and solved numerically using a computer.

After several attempts to apply the model to the Menomonee River Watershed, it was concluded that it was not possible to represent the distribution of various land uses in sufficient detail to warrant the use of this type of model. Furthermore, when what was considered to be a representative distribution of land uses was selected, it was not always possible to obtain simulated concentrations which were representative of field conditions.

A lumped parameter model developed by Gelhar and Wilson (4) proved to be better suited for application to the Menomonee River Watershed.

Gelhar-Wilson Model

Because the aquifer is treated as a point in space, only average values of aquifer parameters are needed as input. Likewise, the model computes spatially averaged values for the elevation of the water table and concentration. As pointed out by Gelhar and Wilson (4), the justification for using a lumped parameter model is that when long-term basin wide changes in groundwater quality are desired, spatial variation becomes less important than temporal variation. The fluctuation of the water table is simulated mathematically by the following equation:

$$n \frac{dh}{dt} = -q + \varepsilon + q_r - q_p \qquad \text{Eq. (3)}$$

where

h	average thickness of the saturated zone
n	average effective porosity
ε	natural recharge rate
q	natural outflow from the aquifer
q_r	artificial recharge/unit area
q_p	pumping rate/unit area
t	time

It can be demonstrated that $q = a(h - h_o)$ where h_o is the elevation of the river and $a = 3T/L^2$ where

$T = h_oK$	transmissivity
K	hydraulic conductivity
L	length of the aquifer

The change in concentration is represented by an equation of the form:

$$nh\frac{dc}{dt} + (\varepsilon + q_r + \alpha nh)c = \varepsilon c_L + q_r c_r \qquad \text{Eq. (4)}$$

where

c	concentration
c_L	concentration of the natural recharge
c_r	concentration of the artificial recharge
α	a first order rate constant which accounts for degradation of the contaminant

Dispersion is assumed to be negligible which is a reasonable assumption if only regional average concentrations are sought.

The hydraulic response time and the solute response time are measures of the lag observed in the response of the system to a given input. Hydraulic response time (t_h) is defined as follows:

$$t_h = n/a \text{ where } a = 3T/L^2 \qquad \text{Eq. (5)}$$

and solute response time (t_c) is defined as:

$$t_c = nh_o/\varepsilon_o \qquad \text{Eq. (6)}$$

where ε_o is the initial recharge rate. In general t_c is time dependent but can be estimated from Eq. (6).

Gelhar and Wilson (4) based their model on the concept of a well-mixed linear reservoir. They postulate that aquifer response to a given input will be similar to the response of a well-mixed linear reservoir (Fig. III-1). They show that the concentration of water leaving the aquifer is representative of the average concentration within the aquifer. Therefore, such a model is ideally suited for determining the quality of groundwater discharging to surface waters. The model is solved by writing Eqs. (3) and (4) in finite difference form:

$$h_{i+1} - h_i = \Delta t[(h_o - \frac{h_{i+1} + h_i}{2})\frac{1}{t_n} + \frac{\varepsilon_i + q_{ri} - q_{pi}}{n}] \qquad \text{Eq. (7)}$$

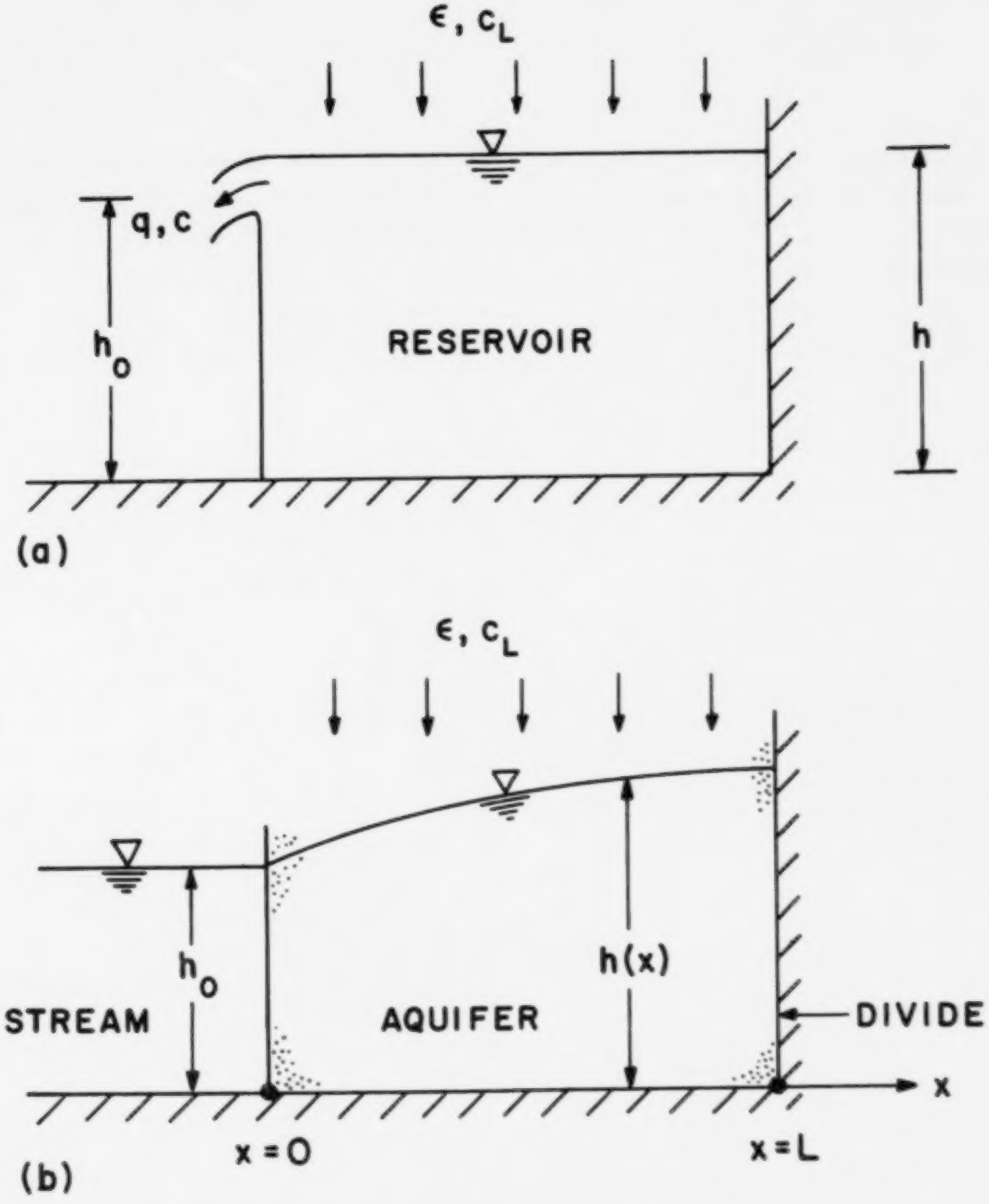

ε, c_L
q, c
h_o
RESERVOIR
h
(a)
ε, c_L
h_o
STREAM
AQUIFER
h(x)
DIVIDE
x
x = 0
x = L
(b)

Fig. III-1. Physical basis for the Gelhar-Wilson model.

$$c_{i+1} - c_i = \frac{\Delta t}{n}[(\varepsilon_i + q_{ri})(\frac{c_{i+1} + c_i}{2}) - (\varepsilon_i c_{Li} + q_{ri} c_{ri})] (\frac{2}{h_{i+1} + h_i})$$

Eq. (8)

In this way, h_o, ε_i, q_{ri}, q_{pi}, c_{Li}, c_{ri} are allowed to vary with time. A computer program written in Fortran was developed to solve Eqs. (7) and (8) with $q_{ri} = q_{pi} = 0$. The program and documentation are included in Appendix III-A.

III-5. PROCEDURES

Field data (1) suggested that chlorides are the major contaminant carried to the river system in groundwater. Eisen and Anderson (1) reported that the amount of chloride discharged to the river in groundwater is a significant percentage of the total chloride in surface water during baseflow conditions. Because chloride concentrations increased markedly during winter months and were especially elevated near highways, it was concluded that road salt runoff is the source of most of the chlorides (1;3). Because of its relative importance compared to other ions, chloride is the only ion considered in the application of the model to the Menomonee River Watershed.

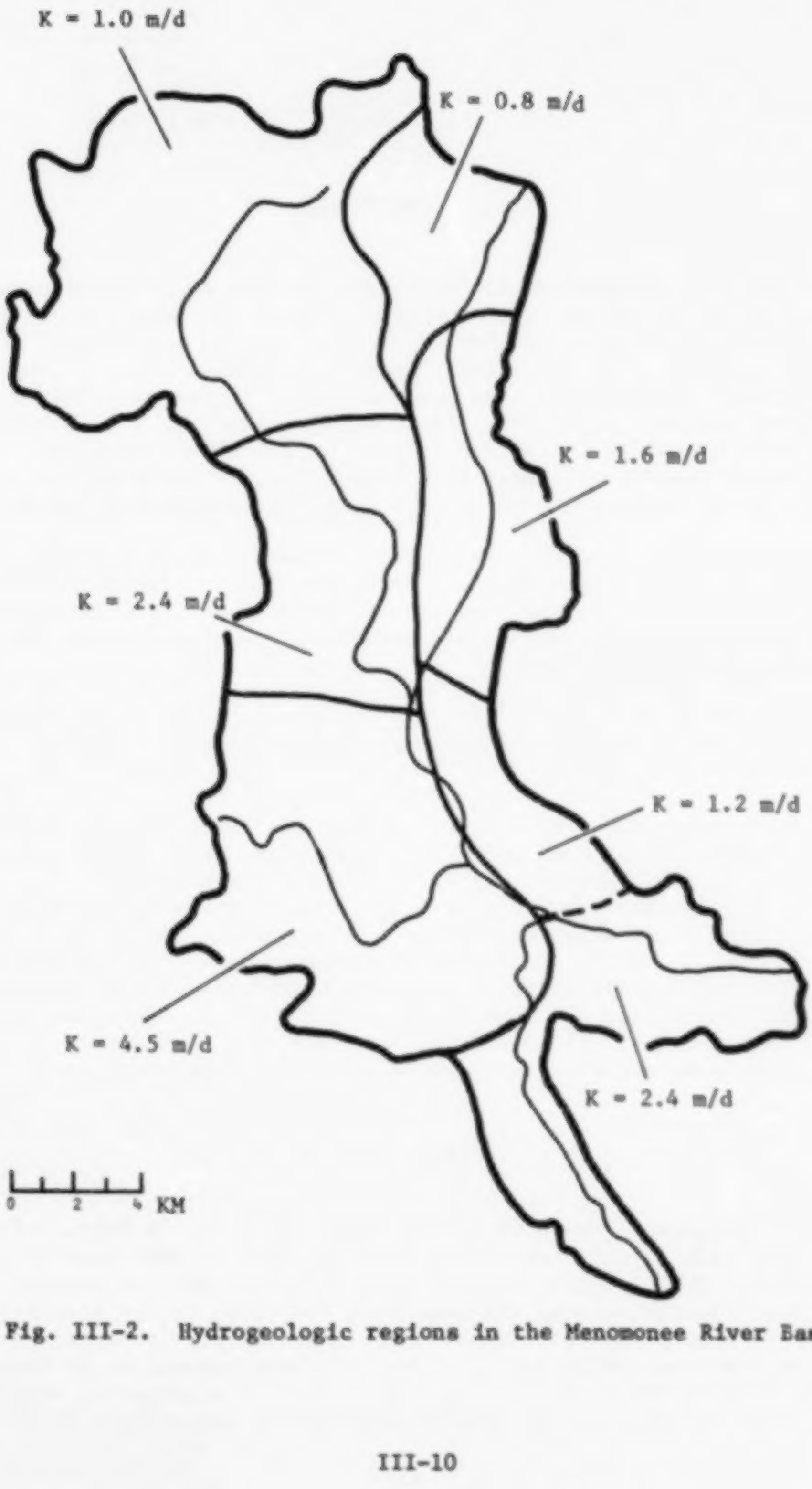
The model can be used for other ions. However, in most modeling applications to date, attention has been restricted to consideration of conservative ions like chloride and nitrate because of the difficulties involved in quantifying the rate at which chemical reactions occur when nonconservative ions are involved.

Definition of Areas for Modeling

For the purposes of the modeling effort, the Watershed was divided into eight areas with similar land use and hydrogeology. Fig. III-2 shows the hydrogeologic regions based on similar hydraulic conductivity. Fig. III-3 shows the modeling areas which include three heavy urban areas (HU-1, HU-2, HU-3), one light urban area (LU-1), two suburban areas (SU-1, SU-2) and two rural areas (R-1 and R-2). Locations of observation well sites are also shown in Fig. III-3 while chloride concentrations observed in the field at each of these well sites are summarized in Table III-1. Data were taken from Eisen and Anderson (1). It is evident that there is considerable variation within a given area and even among wells within a single well site.

Input Data

Aquifer parameters for each of the areas are given in Table III-2. SU-1 West and SU-1 East refer to the areas west and east of the river in area SU-1. Each subarea of SU-1 is characterized by a different aquifer length. The aquifer length is the average distance from the river to the boundary of the area. In the formulation of the model one boundary of the aquifer was taken to be the river while the other boundary was assumed to be located at a groundwater divide (Fig. III-1). In southeastern Wisconsin the shallow aquifer system consists of the glacial aquifer and the Niagara dolomite. The



K = 1.0 m/d
K = 0.8 m/d
K = 1.6 m/d
K = 2.4 m/d
K = 1.2 m/d
K = 4.5 m/d
K = 2.4 m/d
0
2
4
KM

Fig. III-2. Hydrogeologic regions in the Menomonee River Basin.

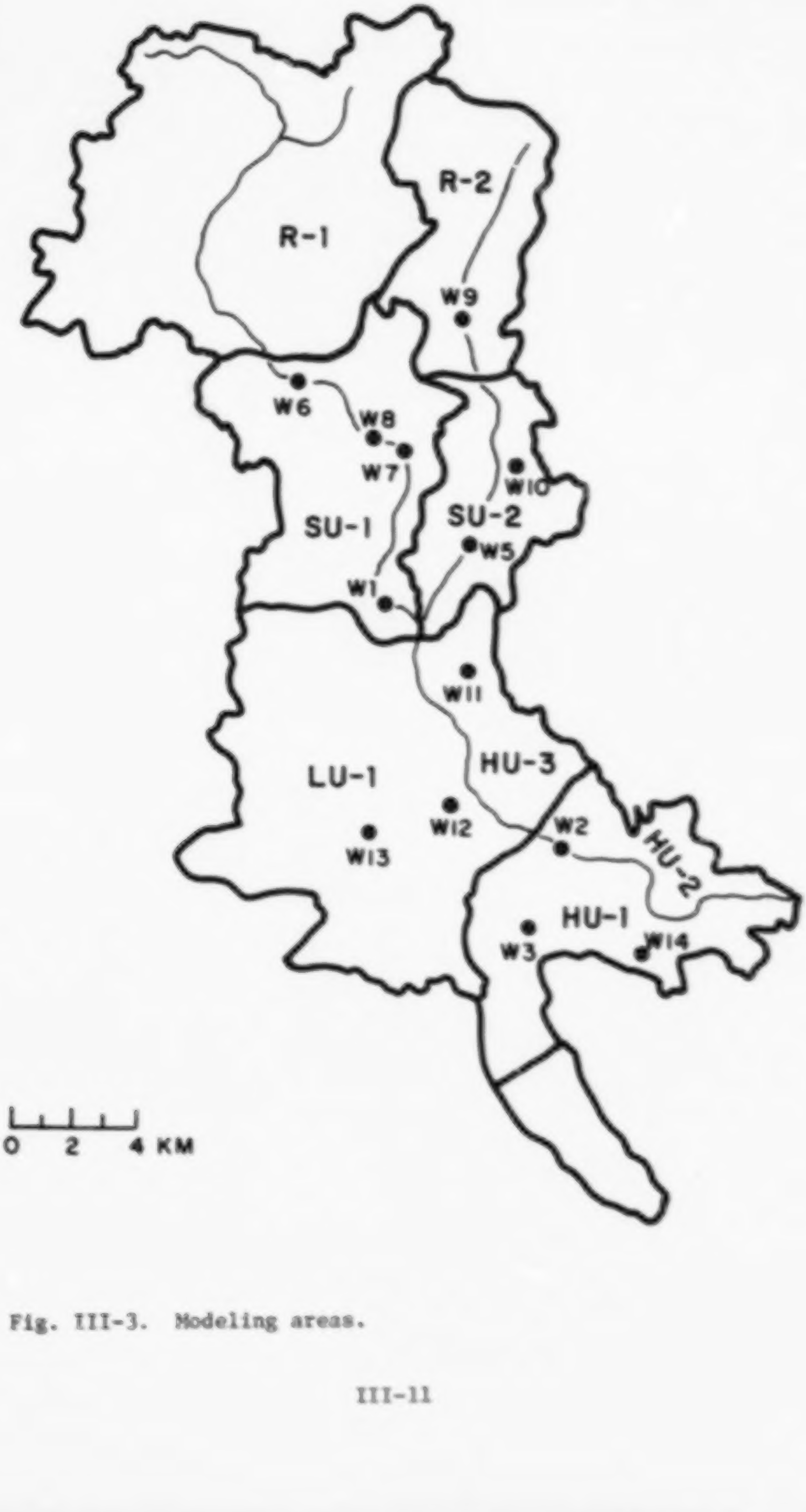

R-1
R-2
W9
W6
W8
W7
W10
SU-1
SU-2
W5
W1
W11
HU-3
LU-1
W12
W2
HU-2
W13
HU-1
W3
W14
0 2 4 KM

Fig. III-3. Modeling areas.

Table III-1. Summary of field data

Well Site	Depth, m	Distance from river, m	Average Cl, mg/L				Average annual Cl, mg/L
			Fall	Winter	Spring	Summer	
Area HU-1							
2-a West	7.8	48	35	100	65	60	65
2-b West	4.4	16	320	550	365	385	405
3-a	6.0	3,200	100	340	-	480	307
3-b	9.0	3,200	100	212	-	-	156
14	8.9	24,000	13	43	13	9	20
Area HU-2							
2-a East	6.5	4.8	142	195	120	132	147
Area HU-3							
11-a	13.1	2,240	-	110	-	62	86
11-b	6.2	2,240	150	290	205	165	203
Area LU-1							
12-a	8.4	960	110	-	-	-	110
12-b	2.9	960	5	-	-	-	5
13-a	8.4	3,480	65	80	89	80	79
13-b	2.9	4,480	73	105	99	95	93
13-c	8.2	4,480	40	-	35	49	41
13-d	2.9	4,480	58	33	85	82	64
Area SU-1 West							
1-a	8.9	13.5	40	49	-	28	39
6-a	16.2	10.5	62	70	-	75	69
6-b	9.6	10.8	90	198	185	99	143
7-a	7.1	6.0	12	280	108	110	128
7-b	2.6	6.3	-	114	178	96	129
7-c	3.5	105.0	-	132	118	70	107
Area SU-1 East							
1-a	7.7	3.0	150	398	-	299	282
1-b	5.3	3.6	320	360	297	228	301
1-c	5.9	28.5	230	400	160	120	228
6-a	7.1	3.9	165	140	-	90	132
6-b	10.2	3.9	42	134	73	122	93
7-a	9.2	5.4	40	65	112	100	79
7-b	5.0	5.4	9	495	55	42	150
8	4.1	4.5	-	32	19	8	20
Area SU-2							
5-a	5.7	2.7	6	33	35	10	21
5-b	4.1	39.0	440	590	350	583	491
5-c	4.1	3.6	153	408	612	416	397
5-d	6.6	3.9	130	420	780	-	443
10	130.0	1,500.0	6	9	12	10	9
Area R-2							
9	2.9	4.5	45	58	23	9	34

Table III-2. Aquifer parameters

Area	Hydraulic response time, years	Solute response time, years	Aquifer length, m	Hydraulic conductivity, m/day	Winter loading rate of chloride, g/m^2/month
HU-1	191	1000	6100	2.4	57
HU-2	29	1000	2400	2.4	57
HU-3	75	1000	2700	1.2	35-57
LU-1	146	23	7300	4.5	12
SU-1 West	67	100	3600	2.4	3.5-5
SU-1 East	74	100	1200	2.4	3.5-5
SU-2	25	100	1800	1.6	7.7
R-1	284	100	4800	3.0	1.4
R-2	50	100	1800	0.8	1.4

regional groundwater divide for the shallow aquifer is located several kilometers west of the boundary of the Menomonee River Watershed and the regional groundwater flow is basically eastward to Lake Michigan. However, Eisen and Anderson (1) verified that local systems exist in the eastern half of the Menomonee River Watershed and that water flows from the Watershed boundary west to the Menomonee River system and east to the Milwaukee River. It is likely that local flow systems also exist in the upper glacial aquifer in the western portion of the Watershed and that water flows from the boundary of the Watershed east to the Menomonee River system and west to the Fox and Root Rivers. Therefore, the Watershed boundaries were assumed to represent groundwater divides in the shallow aquifer system. In each of the areas the elevation of the water level at the river (h_o) was taken to be 15 m and the initial chloride concentration was estimated to be 10 mg/L. Effective porosity was estimated to be 20%.

Groundwater recharge is low because of the relatively impermeable soils which cover most of the Watershed. Based on data reported by Eisen and Anderson (1), it was estimated that groundwater recharge throughout most of the Watershed was 4% of average yearly precipitation. Average annual precipitation is 74 cm (5). Therefore, groundwater discharge is about 3 cm in an average year. In area LU-1, which has more permeable soils than the rest of the Watershed, it was suggested that groundwater recharge was about 18% of average yearly precipitation or 13 cm (1).

In the heavy urban areas where there is a greater percentage of paved surfaces and a greater potential for surface runoff, it was assumed that groundwater recharge was only 10% of the values computed for suburban and rural areas. Estimates of average monthly recharge were computed and used in the model. However, for the Menomonee River Watershed the groundwater recharge is relatively uniform throughout the year.

Chloride loading rates were estimated from road salt use during the winter of 1968 (6). It was assumed that road salt was applied at this rate continuously begining in 1950, the year which marked a nationwide increase in the use of salts for ice control on highways. Road salt is generally applied from December through March. A lag time of 1 month was allowed for the transit of salts through the unsaturated zone so that recharge of salt-laden water occurred during January through April.

During the period May through December the loading rate was taken to be zero in the heavy urban areas. In the rest of the Watershed it was assumed that there were contributions of chloride from septic tank systems or agricultural land during May through December. However, these loading rates were relatively small in comparison to contributions from road salt runoff.

Surface runoff is significant in the Menomonee River Watershed because of the high percentage of paved surfaces and the relatively impermeable soils. Therefore, it was estimated that only 10% of the road salt reached the water table in the heavy urban areas, 75% in the light urban and suburban areas, and 100% in the rural areas. The fraction of salt reaching the water table is represented in the model by the parameter CF (Table III-A-1). In general, CF will be difficult to determine. In the present study and in Gelhar and Wilson (4), CF was estimated for each land use. In the present study, the model was calibrated using only one yearly average chloride concentration for each land use area. An historical record of chloride concentrations such as that used by Gelhar and Wilson (4) is needed to be certain that the model does simulate the observed concentrations. However, in the present study, CF was the only parameter adjusted during the calibration of the model. All the other parameters could be estimated from field data. Therefore, it is believed that the model simulates the probable response of the system.

III-6. RESULTS AND DISCUSSION

Application of Model to Menomonee River Basin

The simulated chloride concentrations at the end of 28 years of continuous application of road salt and the average concentrations observed in the field during 1977-78 (1) are presented in Table III-3. Chloride concentrations at well sites near the river are representative of the quality of groundwater outflow from the aquifer at that point. If, as assumed in the formulation of the model, the highways are uniformly distributed in each of the modeling areas, the groundwater at discharge points should be representative of average water quality in the aquifer. However, at several places in the Menomonee River Watershed, major highways are located adjacent to the river. Therefore, it is likely that where highways are located close to the river,concentrations at the discharge point will be higher than the average concentration in the aquifer as a whole. This would explain the discrepancy between the simulated concentration for area SU-2 and concentrations observed at well site 5 which is located at a point where a highway crosses the river (Fig. II-7, p. II-8). It is also noteworthy that concentrations at well site 10, an upland well site, are much lower than those measured at site 5. There are no other major highways located near the river in SU-2 and it is likely that the concentration at well site 5 is not representative of the average quality of groundwater discharge into the river in area SU-2.

In area SU-1 major highways parallel both sides of the river (Fig. II-7, p. II-8). The chloride loading rate for area SU-1 was estimated to be 3.5 g/m^2/month, and this produced simulated concentrations of 64 mg/L for SU-1 West and 90 mg/L for SU-1 East. However, field data suggested that the concentrations should be around 89 g/L and 130 mg/L,respectively. When the loading rate was increased to 5 g/m^2/month, the simulated concentrations increased to 89 mg/L and 125 mg/L, respectively. Thus, a higher loading rate can be used to compensate for non-uniform distribution of the contaminant.

No data were available on road salt use in area HU-3. Two estimates for loading rate together with simulated chloride concentrations are given in Table III-3. The average concentration for HU-2 was simulated to be 214 mg/L. The only well site in this area is site W-2 with an average concentration of 147 mg/L. Because this site is located near the northern boundary of area HU-2, W-2 may be more representative of conditions in area HU-3.

Because most of the river well sites were also located near highways, the average chloride concentrations for all the well sites in an area may be more representative of the average concentration in each area than the concentrations of chloride in groundwater adjacent to the river. Therefore,

Table III-3. Simulated chloride concentrations compared to field data*

Area	(1) Yearly average Cl concentrations at upland well sites, mg/L	(2) Yearly average Cl concentrations at well sites near the river, mg/L	(3) Average for the area, mg/L	(4) Chloride loading rate, $g/m^2/month$	(5) Simulated Cl concentrations, mg/L
HU-1	Site W3 246 Site W14 20	Site W2 West 235	167	57	187
HU-2	---	Site W2 East 147	---	57	214
HU-3	Site W11 145	---	---	57 35	205 150
LU-1	Site W13 71	Site W12 58	64	12	52
SU-1 West	---	Site: W1 W6 W7 39 106 121	89	3.5 5.0	64 88
SU-1 East	---	Site: W1 W6 W7 W8 270 113 115 20	130	3.5 5.0	90 125
SU-2	Site W10 9	Site W5 338	174	7.7	165
R-1	---	---	---	1.4	23
R-2	---	Site W9 34	---	1.4	42

*Compare columns 2 and 3 with column 5.

area averages are also given in Table III-3. It should also be noted that the model does not reproduce the marked seasonal fluctuations observed in the field. Seasonal fluctuations would be expected to be most pronouned close to the source of contamination. Therefore, well sites near highways probably exhibit more seasonal fluctuation than is average for the aquifer as a whole. Moreover, because of the long response times of the aquifer (Table III-2), the seasonal fluctuation in loading rates is damped as the solute is transported through the aquifer.

Although there are discrepancies between simulated concentrations and field values, which in most cases were probably caused by proximity of the well sites to highways, the model simulates the situation well enough to provide some insights into the probable response of the system to land use changes or changes in loading rates. The responses of the systems to application of road salt at the 1968 rates for the period 1950 to 2060 are shown in Fig. III-4. The results of the model suggest that except for area R-1 concentrations observed in 1978 are not steady-state values and can be expected to increase steadily for several years if the application rate of salt remains at least as high as during 1968.

Groundwater discharge rates (q^*) can be computed from the following formula:

$$q^* = \varepsilon L \ell \qquad \text{Eq. (9)}$$

where ℓ is the length of the river receiving groundwater discharge. Groundwater discharge rates computed using Eq. (9) agreed with the discharge rates computed from field data (1).

Loading rates for each area can be calculated from:

$$L.R. = q^* c \qquad \text{Eq. (10)}$$

where c is average concentration in the groundwater discharge. Loading rates calculated using the average concentrations generated by the model were lower than those computed by Eisen and Anderson (1). In calculating loading rates, concentration data was used from the well which exhibited the highest chloride concentration for the site rather than the average value for all the wells in a site (1). Thus, the estimates are conservative in that they represent maximum possible loading rates. Loading rates for area HU-1 or HU-2 were not computed because of a lack of field data (1).

In the present study and in the Eisen and Anderson (1) study, the highest loading rates for 1978 were generated from area LU-1 which also had the highest groundwater discharge rate although the average chloride concentration was not particularly high. Fig. III-4 shows that concentrations will increase at a greater rate in suburban areas than in area LU-1 if salting continues at the present rate. In future years, loading rates from areas SU-1 and SU-2 could be expected to surpass LU-1 assuming that q^* remains constant.

Some of the communities in areas LU-1 and SU-1 West currently rely on groundwater for municipal water supply and according to Cherkauer and Bacon (7) could continue to utilize groundwater in the future. In two areas of SU-1 where there is heavy pumpage for municipal use, the water table is

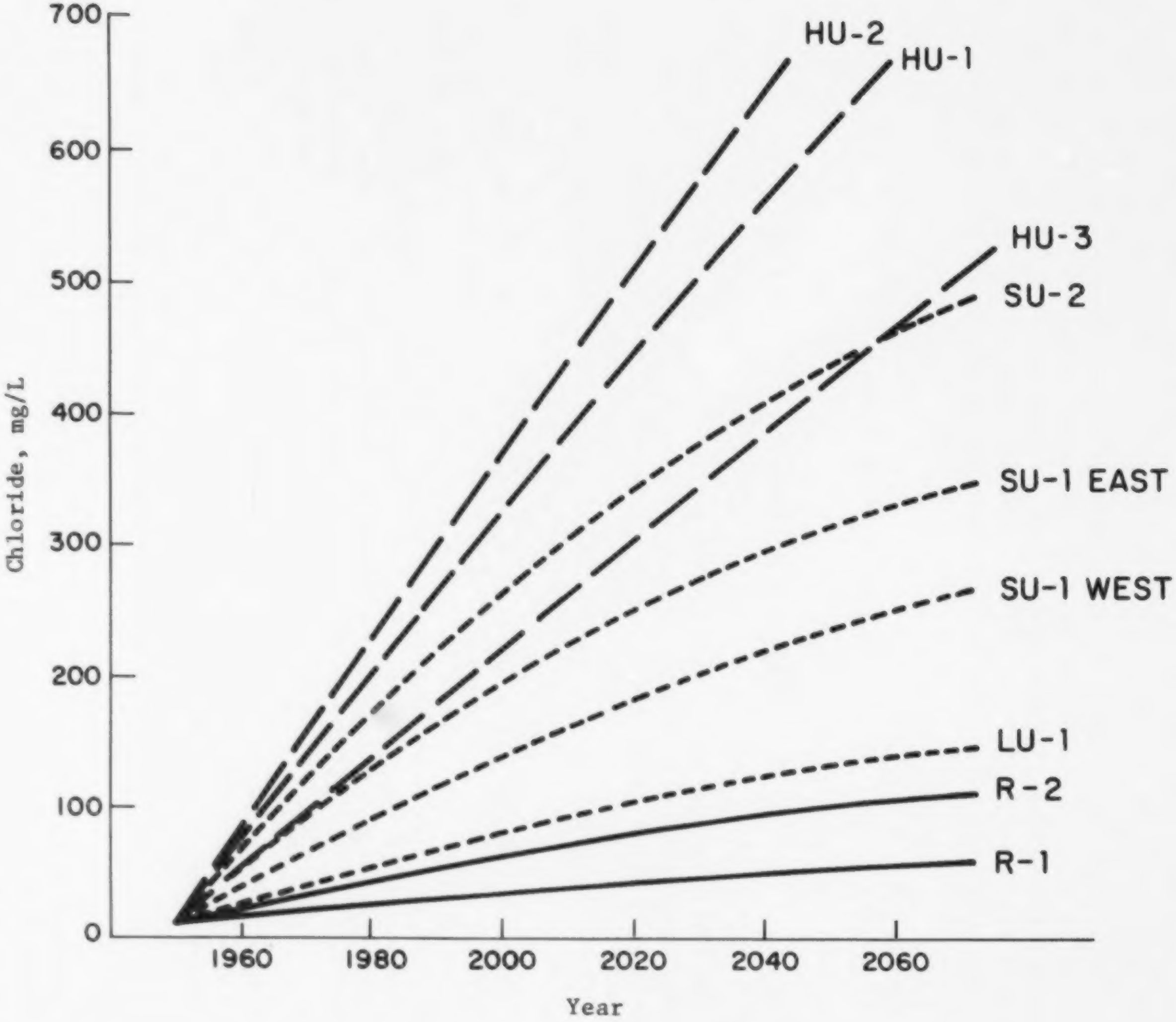


Fig. III-4. Responses of the aquifer in each of the modeling areas.

located below the stream bed (1). Pumping rates could increase to the point where the aquifer no longer contributes groundwater to the stream anywhere within area SU-1, that is, q* would be zero. However, reduction of salt usage might still be a concern in order to protect the quality of groundwater for municipal use. Communities in area LU-1 and SU-1 West currently utilize deep wells which yield water with concentrations of chloride lower than those reported here for the shallow aquifer. However, water in the shallow aquifer potentially could contaminate deeper groundwater supplies. If in 1980, salt use were reduced in areas SU-1 West, SU-2 and LU-1 to the application rate used in rural areas (1.4 g/m^2/month), the systems would respond as shown in Fig. III-5.

Extrapolation to Other Watersheds

Nature of contamination

Hoffer and Anderson (3) suggested a methodology for identifying the importance of potential sources of groundwater contamination in other watersheds in the Great Lakes Basin. The nature and degree of groundwater contamination can be expected to vary depending on the distribution of land use and the hydrogeology of the Watershed, especially the permeability and thickness of the shallow aquifer and the recharge rate.

The contaminants which are most likely to be transported through the groundwater system to surface waters are nitrate and chloride. However, at least two studies on urban hydrogeology have found increased concentrations of sulfate in groundwater after urbanization. In the Menomonee River Watershed, the average sulfate concentration was 188 mg/L (1) while the regional average for southeastern Wisconsin is around 63 mg/L (8). In the Chicago area, Long and Saleem (9) reported that the average concentration of sulfate in groundwater increased from 130 mg/L in the 1930's to 320 mg/L in 1973. In the Menomonee River Watershed, the highest concentrations of sulfate occurred in the heavily urbanized portions of the Watershed. Concentrations were highest during the spring when higher rates of precipitation may have facilitated percolation of industrially-produced sulfate residues to the water table. However, it is likely that there are other sources such as leachate from landfills which contribute to the increases in sulfate after urbanization.

Concentrations of nitrate in groundwater in the Menomonee River Watershed were usually below 0.4 mg N/L. However, in other watersheds with more permeable soils and a greater density of residential area relying on septic tank systems or a greater percentage of irrigated agricultural land, contamination by nitrates may be a cause of concern.

In addition to road salt runoff, another source of chloride contamination is water used to regenerate water-softening units. According to Cherkauer and Bacon (7), an average home in southeastern Wisconsin uses around 350 kg of salt/year for water softening. This amounts to about 200 kg of chloride in waste water. In the Menomonee River Watershed, most of

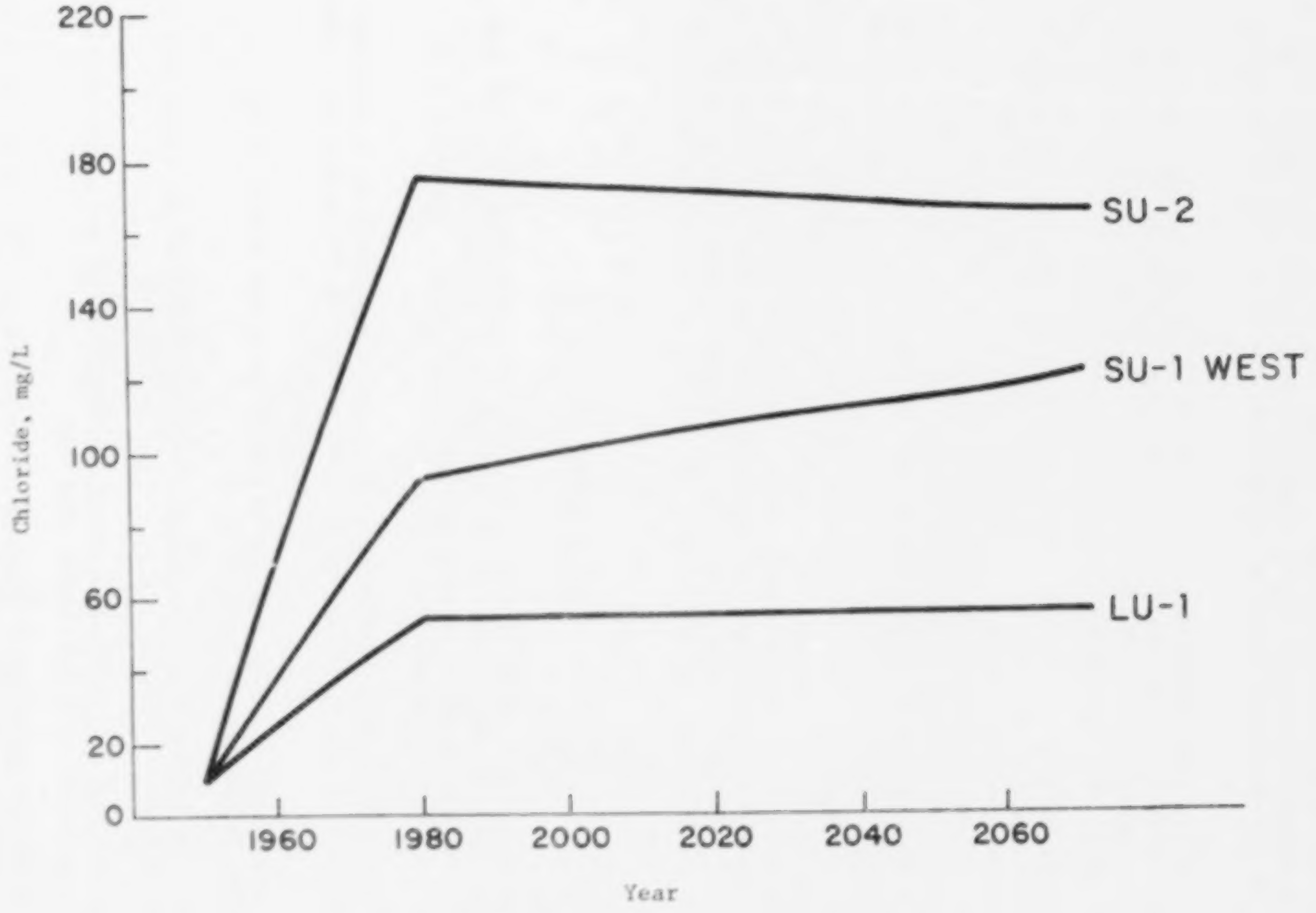


Fig. III-5. Responses of the aquifer in areas LU-1, SU-1 and SU-2 to a decrease in the rate of application of road salt. In 1980, application rate is decreased to 1.4 g/m^2/ month in each area.

this effluent would be diverted directly to sewage treatment plants rather than recharged to the shallow aquifer. However, in watersheds where there is a more widespread reliance on septic tank systems, significant amounts of chloride may be introduced into the groundwater system from water softening units.

Although the contaminant sources mentioned above and others cited by Hoffer and Anderson (3), may be important in other watersheds, it is expected that in most developing watersheds in the Great Lakes Basin, chlorides from road salt runoff will be a major source of contamination.

The present three-part study of groundwater contributions to surface water quality considered only the groundwater which discharges to the Menomonee River System. However, Cartwright et al. (2) demonstrated that a significant volume of groundwater discharges directly to Lake Michigan in the shoreline area between Waukegan, Illinois and Kenosha, Wisconsin. They estimated that groundwater discharges to Lake Michigan at a rate of 19 cm/yr in the nearshore sandy sediments and at a rate of 0.5 cm/yr in the deep lake clays. Moreover, they found that the chemistry of the lake water was distinctly different from the groundwater chemistry and suggested that certain ions present in the upper sediment may have been in solution in groundwater and precipitated out at the groundwater-lake boundary. Most notably zinc, boron and manganese were present in the groundwater but were below detection limits in the lake water. The results of their study suggest that direct groundwater discharge to the Great Lakes should not be automatically disregarded.

Use of model

The Gelhar-Wilson model (4) is suited ideally to estimate the concentrations of contaminants in groundwater discharging to a stream and to study the effects of land use change on average groundwater quality. The major input parameters to the model are:

a. Average hydraulic conductivity (K) - may be available from previous regional studies or can be estimated from information on the lithology of the aquifer.

b. Groundwater recharge rate (ε) - can be estimated from data on precipitation or baseflow.

c. Aquifer length (L) - the length of the aquifer from the river to a groundwater divide.

d. Loading rate (c_L) - can be estimated from data on the amount of the contaminant generated by a particular land use.

e. Percent of contaminant reaching the water table (CF) - will depend on part on the importance of overland flow in the watershed; estimates can be made for each land use.

Other parameters are given in the Appendix III-A.

The model solves for the average elevation of the water table and the average concentration of the contaminant within each area modeled. Loading rates for each land use area can be estimated from Eq. (10); where (q*) is the groundwater discharge rate and (c) is the average concentration computed by the model. Thus, the model can be used as a management tool to estimate which area in a particular watershed presently discharges the greatest volume of the contaminant to a stream and to predict which area is likely to discharge the greatest volume in the future.

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APPENDIX III-A. COMPUTER PROGRAM

Table III-A-1. List of parameters

NEND	Number of cycles consisting of NYT years each
NYT	Number of years in a cycle up to 20
NMO	Number of months in a cycle up to 240
PK	Average hydraulic conductivity (length/day)
POROS	Average porosity
L	Aquifer length
T	Average transmissivity (length^2/month)
HO(I)	Elevation of the water level in the river
HI	Default value for HO(I)*
H(I)	Average elevation of the water table for the time step
Q(I)	Groundwater recharge rate (length/month)
P(I)	Annual precipitation
PP	Default value for P(I)
RCOEF	Percent of annual precipitation reaching the water table
RF(I)	Percent of annual groundwater recharge occurring in a given month
CI	Initial concentration
C(I)	Concetration for the time step
WINLD	Winter loading rate (mass/length^2/month)
BKGD	Loading rate for the rest of the year (mass/length^2/month)
CLOAD(I)	Loading rate for the time step (mass/length^2/month)
CF	Percent of contaminant reaching the water table
TH	Hydraulic response time in months
CRT	Estimate of solute response time in months
DELT	Time step in months
HOLD	Elevation of the water table at the end of a cycle
CHOLD	Concentration at the end of a cycle

*In Fortran notation when a ( ) follows a variable name it refers to an array of values.

Table III-A-2. Computer listing

```
   REAL L
   DIMENSION C(240),  O(240), H(240), Q(240), HO(240)
 1,P(20), RF(12), CLOAD(12)
10 FORMAT (3I5)
20 FORMAT (3F10.4)
30 FORMAT (1X,12F10.5)
40 FORMAT (F10.5)
50 FORMAT (1X,12E10.5)
60 FORMAT (' ')
   READ (5,10) NEND,NMO,NYT
   READ (5,20) L,POROS,PK
   READ (5,20) HI,CI,DELT
   READ (5,20) CF,WINLD,BKGD
   READ (5,40) RCOEF
   READ (5,40) PP
   DO 2 MO=1,12
   READ (5,40) RF(MO)
 2 CONTINUE
   DO 1 I=1,NYT
   P(I)=PP
 1 CONTINUE
   DO 4 MO=1,4
   CLOAD(MO)=WINLD
 4 CONTINUE
   DO 5 MO=5,12
   CLOAD(MO)=BKGD
 5 CONTINUE
   C(1)=CI
   DO 6 I=1,NMO
   HO(I)=HI
 6 CONTINUE
   T=PK*HO(1)*30.
   Q(1)=RCOEF*P(1)/12.
   A=3,*T/(L*L)
   H(1)=HO(1)+(Q(1)/A)
   TH=POROS/A
   CRT=HI*POROS/Q(1)
   K=1
   WRITE (6,30) (P(I),(=1,NYT)
   WRITE (6,30) (RF(MO), MO=1,12)
   WRITE (6,60)
   WRITE (6,30) RCOEF,CF,WINLD,BKGD
   WRITE (6,30) L,POROS,PK,DELT
   WRITE (6,30) H(1),Q(1),HI,CI
   WRITE (6,50) TH,CRT,T
   DO 100 NSTEP=1,NEND
   NYR=1
   MO=1
   HOLD=H(K)
   CHOLD=C(K)
   DO 3 I=1,NMO
   Q(I)=P(NYR)*RF(MO)*RCOEF
   CO(I)=CLOAD(MO)*CF/Q(I)
   IF(MO.GT.4) CO(I)=BKGD
   A=(HO(I)-(HOLD/2.))/TH
   B=Q(I)/POROS
   H(I)=(DELT*(A+B))
   A=1.+(DELT/(2.*TH))
   H(I)=(H(I)+HOLD)/A
   C(I)=Q(I)*(CO(1)-(CHOLD/2.))
   A=H(I)+HOLD
   C(I)=C(I)*((2.*DELT)/(POROS*A))
   A=1.+(DELT*Q(I)/(POROS*A))
   C(I)=(C(I)+CHOLD)/A
   MO=MO+1
   IF(MO.EQ.13) NYR=NYR+1
   IF(MO.EQ.13) MO=1
   HOLD=H(I)
   CHOLD=C(I)
 3 CONTINUE
   K=NMO
   WRITE (6,60)
   WRITE (6,30) (C(I),I=1,NMO)
   WRITE (6,60)
   IF (NSTEP.NE.NEND) GO TO 100
   WRITE (6,30) (H(I),I=1,NMO)
   WRITE (6,60)
   WRITE (6,30) (Q(I),I=1,12)
   WRITE (6,50) (CO(I),I=1,12)
   WRITE (6,60)
   WRITE (6,60)
100 CONTINUE
   STOP
   END
```